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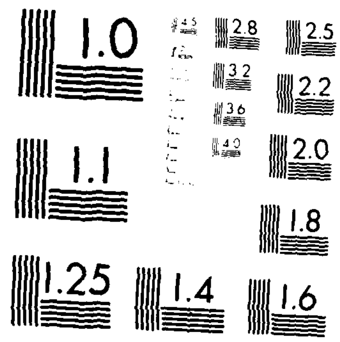

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TECHNICAL
MEMORANDUM
NCSC TM 370-83

MARCH 1983

GROUND TRUTH ANALYSIS SUPPORTING THE HIGH RESOLUTION FLYOVER

DANIEL F. LOTT

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PANAMA CITY, FLORIDA 32407

CAPT RAYMOND D. BENNETT, USN
Commanding Officer

GUY C. DILWORTH
Technical Director

ADMINISTRATIVE INFORMATION

This work provided ground truth measurements in support of the High Resolution Flyover (NAVAIR Task No. A370370G/076B/1F590550-000). Ground truthing was provided by the Environmental Sciences Division (Code 734) to the Coastal Warfare Department (Code 772) under Work Unit 81009-01.

Released by
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March 1983

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Ground truth measurements were collected during high resolution flyover tests designed to maximize resolution of a multispectral scanner. Tests were conducted on 27 and 31 August and 1 September 1981 at sites providing different water mass types and bottom reflectances. Measurements of water level, wave heights, surface and water column temperatures, wind speed and direction, solar radiation, diffuse and beam attenuation coefficient, and secchi depth were obtained. The environmental conditions which affected scanner performance are summarized.

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SUMMARY

Local Gulf and bay waters were murkier than normal during high resolution flyovers conducted 27 August through 1 September 1981. The murky water was a severe system test of sensor performance and limited the accomplishment of experimental objectives.

At sites within St. Andrew Bay, values of α and K ranged two to three times worse than expected. These values represented excessive amounts of turbid material (both in suspension and solution) contained in local rain-water runoff. Wind waves mixed shallow near-shore waters thoroughly, thereby placing substantial quantities of fine sediment into suspension and increased sea surface roughness, thus decreasing information available to the sensor.

At the test site in the Gulf of Mexico, values of α and K ranged two to four times worse than normal, conditions being somewhat better at mid-depths than near the sea floor or surface. Motions associated with wind waves and swell stirred bottom sediments into suspension, while prevailing winds diverted St. Andrew Bay effluent toward the test site on successive ebb tides. The brackish effluent was lighter than underlying sea water, so it spread out across the surface of the nearby Gulf as a thin layer of brownish-green water containing materials both in suspension and solution. The resultant stratifications, coupled with prevailing surface waves, substantially reduced the level of reflected radiation and the system's capability to interpret received optical signals.

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INTRODUCTION

A vast quantity of information can be extracted through analysis of light reflected from the ocean's surface using remote sensing. With proper processing, information on water depth, temperature, color, diffuse attenuation coefficient, turbidity, and currents can be inferred from reflected light.[1 2 3 4 5 6]

In August 1981, a remote sensing experiment was conducted in the vicinity of the Naval Coastal Systems Center (NCSC) at Panama City, Florida. Known as the High Resolution Flyover, this experiment was conducted jointly by NCSC and the Environmental Research Institute of Michigan (ERIM). The primary objectives were to (1) develop new information from reflected light to produce a map of the sea floor by correcting for the effects of water column characteristics and (2) determine the probability of detection of objects placed on the sea floor. The effort evaluated a passive sensor system flown at speeds and altitudes yielding maximum resolution. Hardware, test procedures, and data analysis were ERIM responsibilities. While ERIM personnel operated the passive sensor system during flyovers of selected test areas, NCSC personnel collected ground truth measurements using conventional water quality instrumentation. System performance could then be assessed by comparing actual measurements to those derived from reflected light.

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[1]Naval Coastal Systems Center Technical Memorandum TM 240-78, "Ground Truth Analysis of Multispectral/Laser System Experiment," by R. A. Arnone, September 1978.

[2]Morel, Andre and Prieur, L., "Analysis of Variations in Ocean Color," Limnol and Oceanogr, Vol. 22(4), 709-721, 1977.

[3]Esaias, W. E., "Remote Sensing in Biological Oceanography," Oceans, Vol. 24(3):32-38 (81).

[4]Austin, R. W. and Petzold, T. J., "The Determination of the Diffuse Attenuation Coefficient of Seawater Using the Coastal Zone Color Scanner," Presented at COSPAR/SCOR/IUCRM Symposium Oceanography From Space; May 26-30, 1980; Venice, Italy.

[5]Aranuvachapun, S. and LeBlond, P. H., "Turbidity of Coastal Water Determined from Landsat," Remote Sensing of Environment, Vol. 84: 113-132 (81).

[6]O'Brien, James J., "The Future of Satellite-Derived Surface Winds," Oceans, Vol. 24(3): 27-31 (81).

The quality and quantity of data available in the reflected light were dependent on atmospheric viewing conditions, test object characteristics, scanner and sensor performance, and marine conditions. This report documents ground truth measurements obtained during the high resolution flyover. These measurements include beam attenuation coefficient (α), diffuse attentuation coefficient (K), Secchi depth, water depth, tide water level variation, wind speed, wind direction, water temperature, solar radiation, and surface wave height.

AREA DESCRIPTION

Two flyovers were made over the western arm of St. Andrew Bay adjacent to NCSC and one over the nearby coastal waters of the Gulf of Mexico. The Gulf test site is shown in Figure 1. These test sites had been used for previous remote sensing experiments, so a limited environmental data base was available.[1] Tests were conducted during the late summer from 27 August through 1 September 1981.

A general area description is provided by Salsman and Ciesluk.[7] This report indicates that summer weather patterns are dominated by the Bermuda high pressure cell located off the Carolina coast. The resulting pressure pattern produces easterly to southeasterly winds in Panama City. During the day, solar radiation heats the air overlying land areas causing it to lighten and ascend, thereby generating a sea breeze. The sea breeze in turn increases humidity and sea surface roughness. As the warmed air rises overland, it cools to form extensive cumuliform clouds producing frequent showers or thunderstorms. By sunset, the sea breeze usually dissipates and Gulf waters calm. This pattern recurs daily unless the area comes under the influence of a tropical depression.

Summertime air temperatures range from 21 to 32°C with occasional highs in the nineties. Winds tend to be light from a southerly direction according to the following frequency. Winds also tend to be lighter at night than day during summers.

Wind Speed (kt)	Frequency of Occurrence (%)
0	20
1-4	14
4-7	24
7-11	32
11-17	15
17-22	5
>22	1

[1] ibid.

[7] NAVCOASTSYSCEN Technical Report TR 377-78, "Environmental Conditions in Coastal Waters Near Panama City, Florida," by G. G. Salsman and A. J. Ciesluk, August 1978.

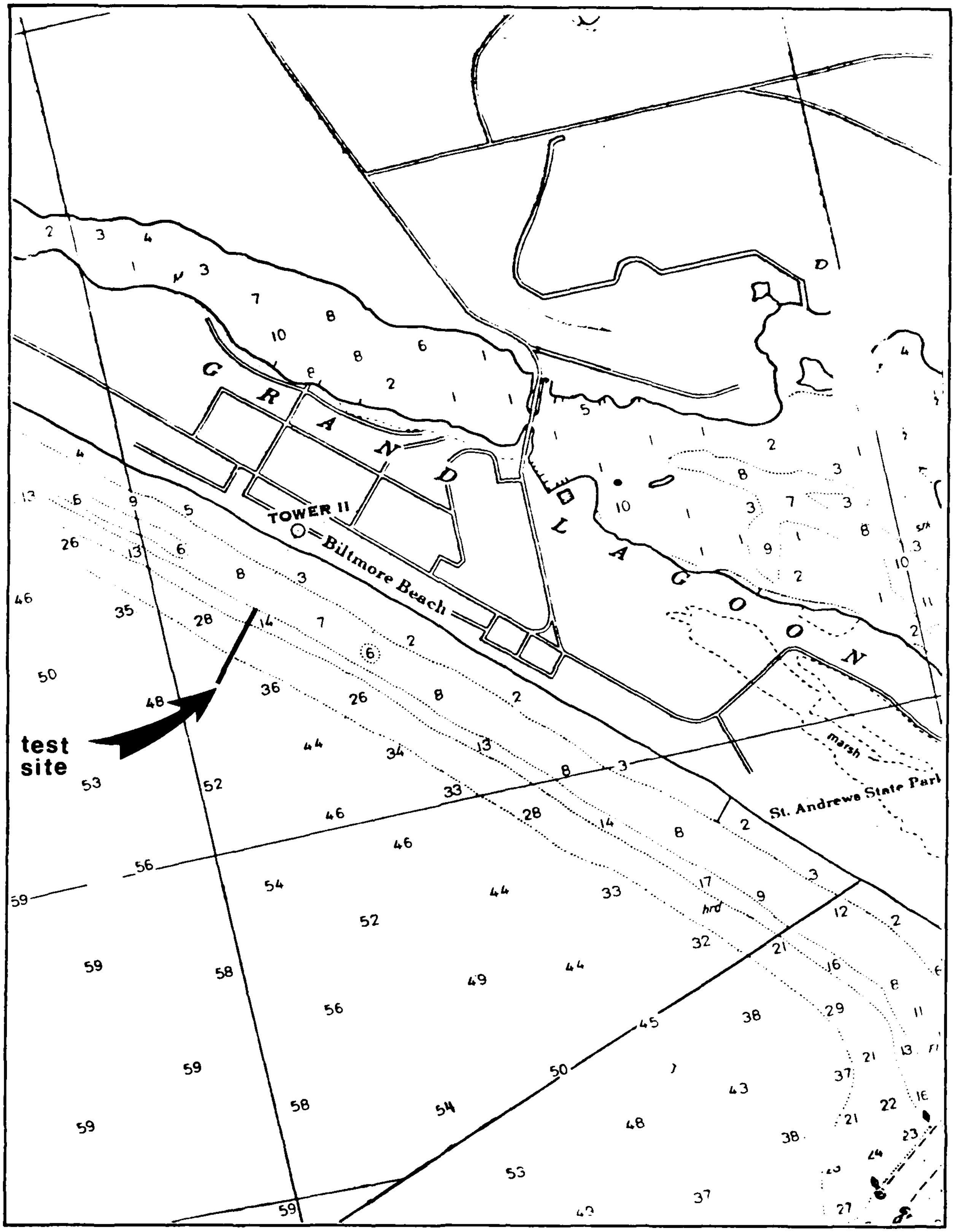

FIGURE 1. LOCATION OF THE GULF TEST SITE NEAR NCSC TOWER II ON BILTMORE BEACH

In August, waves increase from barely discernible ripples in the early morning to wave heights of approximately one-half metre during the afternoon sea breeze. Sea breeze development usually begins about 10 a. m. local time. The sea breeze and any tropical disturbances in the Gulf are the primary generators of surface waves in the test area during summer months. Near shore, Gulf waters tend to be a mixture of bay water and ocean water. Color ranges between brown and blue, shifting toward the latter during droughts and the former during rainy periods.

Wind stress controls water column mixing on the eastern continental shelf.[8] Hoge, et al[9] and Salsman and Tolbert[10] have shown that wind stress also controls mixing in near-shore waters. Since wind is light during summer months, mixing is less evident and the water column becomes stable with significant thermoclines. During dry spells, underwater visibility can reach 5 to 15 metres (with a diffuse attenuation coefficient of 0.4 to 0.6 m^{-1}). Poorer visibility can be expected following periods of heavy rain or when wave action stirs up sediments from the bottom.

The local Gulf sea floor is rather flat and featureless with one to two longshore bars. The shallow portion of the sea floor is composed of fine to medium quartz sand of 0.1 to 0.2 millimetre mean grain diameter. The quantity of fines in Gulf sediments is extremely low and results in a high bottom reflectance. The major feature of the near-shore Gulf bottom is sand ripples. These wave-induced sand ripples average 2.54 centimetres in height and 7 to 13 centimetres in wavelength. Sand ripples exceeding 15 centimetres in height and 0.9 to 1.2 metres in wavelength may form in coarse offshore sands during severe storms.

Although the bay test sites (Figure 2) are subject to essentially the same weather patterns as the Gulf sites, major differences occur in wave, water, and bottom characteristics. Bay waters are composed of fresh water from streams and drainage runoff containing quantities of tannic and humic acids which combine with intruding seawater. Water color is brownish-green. Underwater visibility adjacent to NCSC is 1 to 5 metres with typical alpha values of 1.2 to 2.0 per metre. With excessive runoff from rain, alpha may become greater than 3 and the visibility remain poor for weeks.

Waves within the bay are characteristically wind generated, of short period, and less than 0.3 metre in height. Severe winds may bring white caps

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[8]Alexander, J. E., et al, BLM Contract No. 08550-CT5-30, "Baseline Monitoring Studies, Mississippi, Alabama, Florida, Outer Continental Shelf," 1975-76, Vol. IV, 28 June 1977.

[9]Hoge, F. E., et al, "Water Depth Measurement Using An Airborne Pulsed Neon Laser System," Applied Optics, Vol. 19(6): 871-883 (1980).

[10]Navy Mine Defense Laboratory Report 209, "Surface Currents in the Northeastern Gulf of Mexico," by G. G. Salsman and W. H. Tolbert, August 1963.

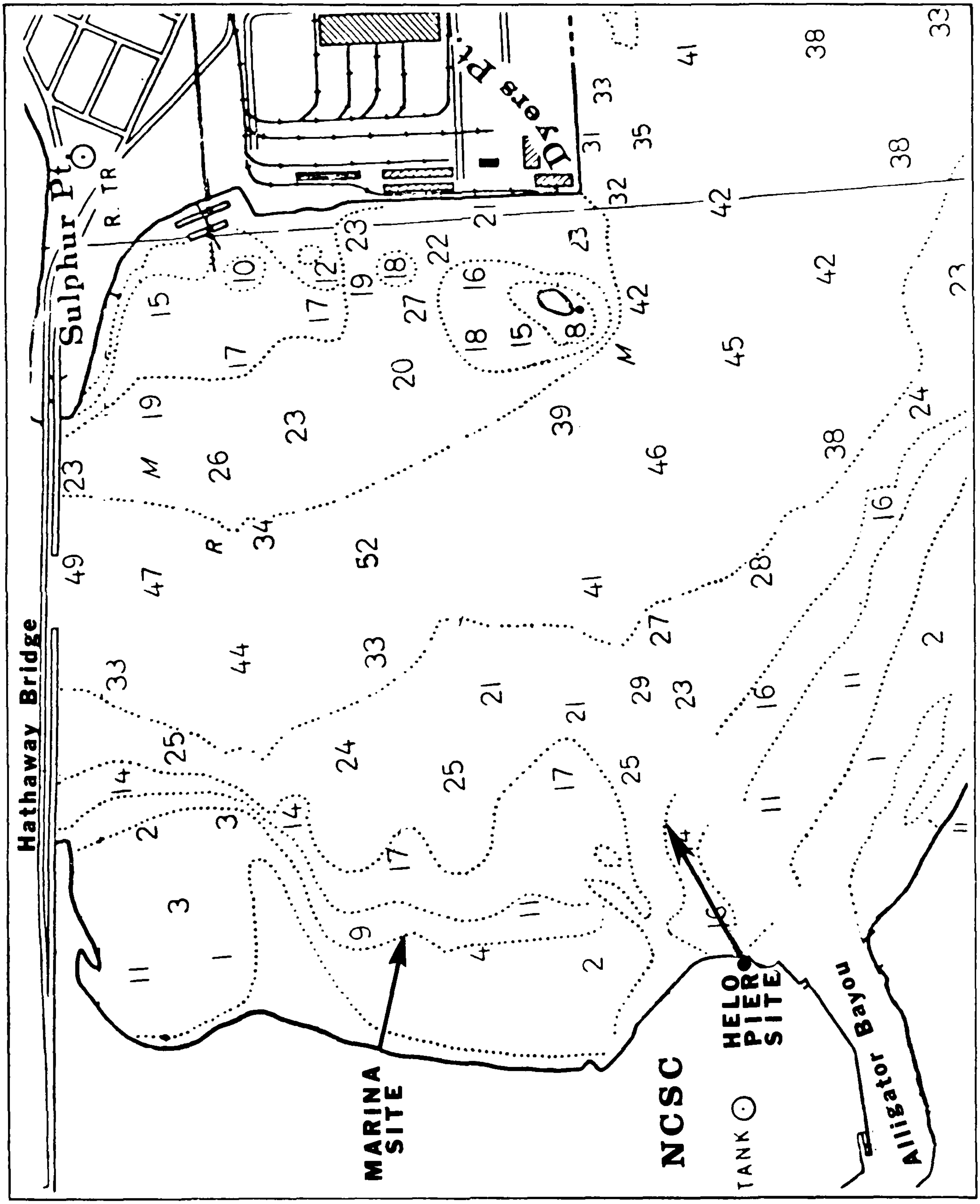


FIGURE 2. BAY TEST SITES AT NCSC HELO PIER AND MARINA

to the bay with waves of 0.6 to 1.2 me es in height. Wave action decreases quickly and dramatically as winds subside.

Bottom conditions at the two bay sites differ significantly. At the helo site (Figure 2), the bottom consists of 90 to 95 percent coarse to medium quartz sand and 50 to 10 percent fine material. A sandbar extends toward the main bay channel and northward in a broad shallow fan-shaped area. The sand contains significant concentrations of shell fragments, particularly in the shallower region where waves strike the shore. Depths increase gradually at this site and bottom reflectance is essentially uniform.

The bottom at the marina site (Figure 2) consists of a narrow band of quartz sand containing significant concentrations of fines near-shore giving way to extensive grass beds composed of shoal (Halodule wrightii) and turtle grasses (Thalassia testudinum) located between the 1- and 6-foot bathytherms. As depth increases, grasses diminish and the bottom consists of sand overlain with silt and scattered shell fragments in deeper water offshore. The area thus provides both high and low reflectances with increasing depth.

TEST DESCRIPTIONS

TEST SITES

Gulf Site

The Gulf test site was located approximately 152 metres southwest of NCSC's Tower II. (Objects 1.6 metres in length and 0.5 metre in diameter were placed at depths indicated in Figure 3.) Position of each object was marked with floats 1.2 metres by 2.4 metres by 12.7 centimetres painted international orange and individually coded with paterns whose minimum width was 15 centimetres (Figure 3). Floats were deployed on two-point moors to ensure fixed distance from the object and fixed bearing; i.e., west of the object.

On both days of Gulf operations, extremely large numbers of Stomolophus meleagris (Cabbagehead or Cannonball Jellyfish) and Chrysaora quinquecirrha (Sea Nettle Jellyfish) were present in the test area. The jellyfish were sufficiently large to be detected and would appear as noise in the digital data.

Bay Site

Two different layouts were used at the helo pier test site. The test field was laid out as indicated in Figure 4 for the 27 August flyover; Figure 5 shows the layout for the 1 September operations. In both cases, test panels 30.5 centimetres by 30.5 centimetres of 3.2-millimetre steel plate painted olive green were placed on the bottom at the depths indicated. Positions were marked by buoys 1.2 metres by 2.4 metres by 12.7 centimetres

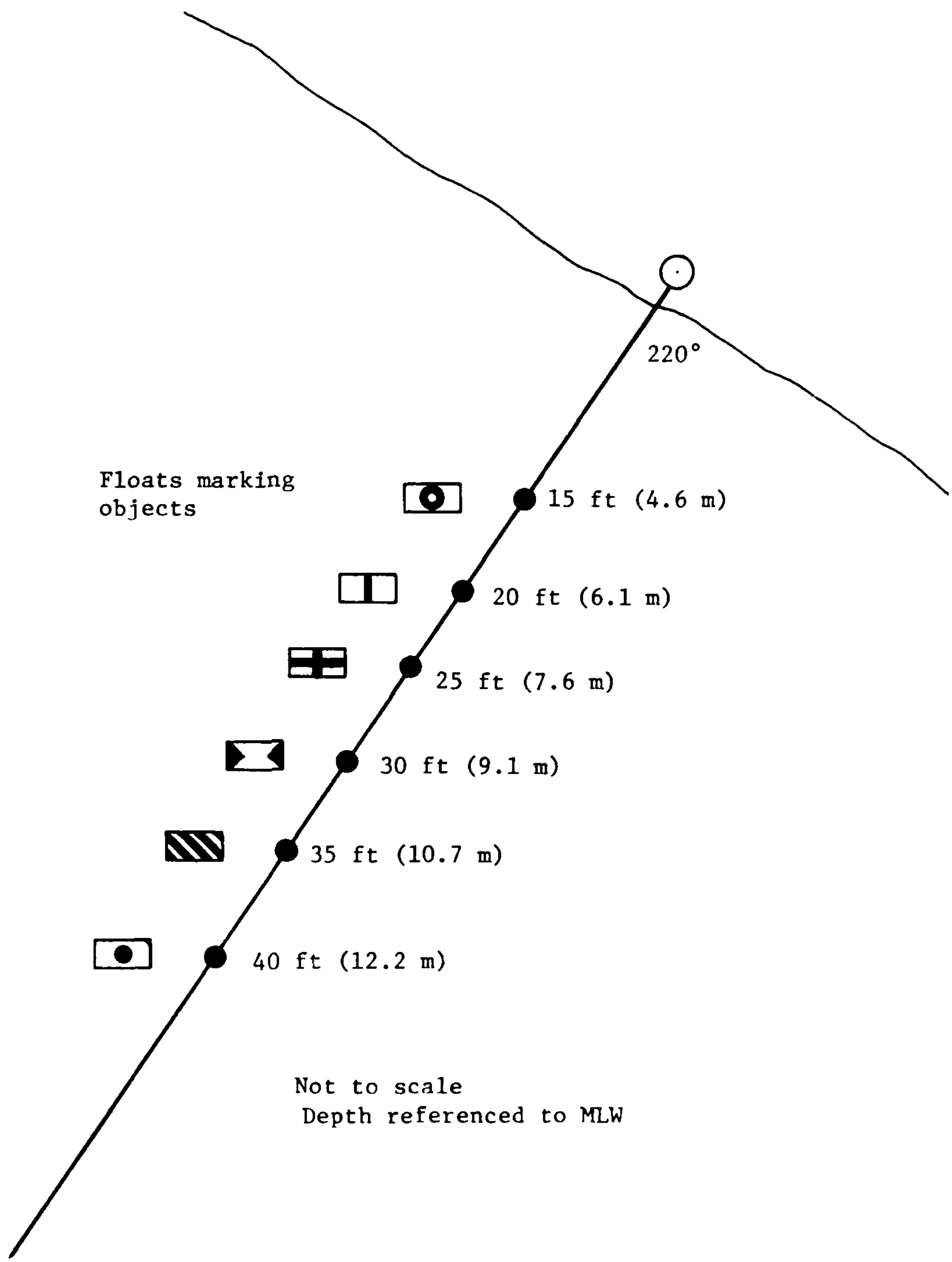


FIGURE 3. TEST LAYOUT AT THE GULF TEST SITE

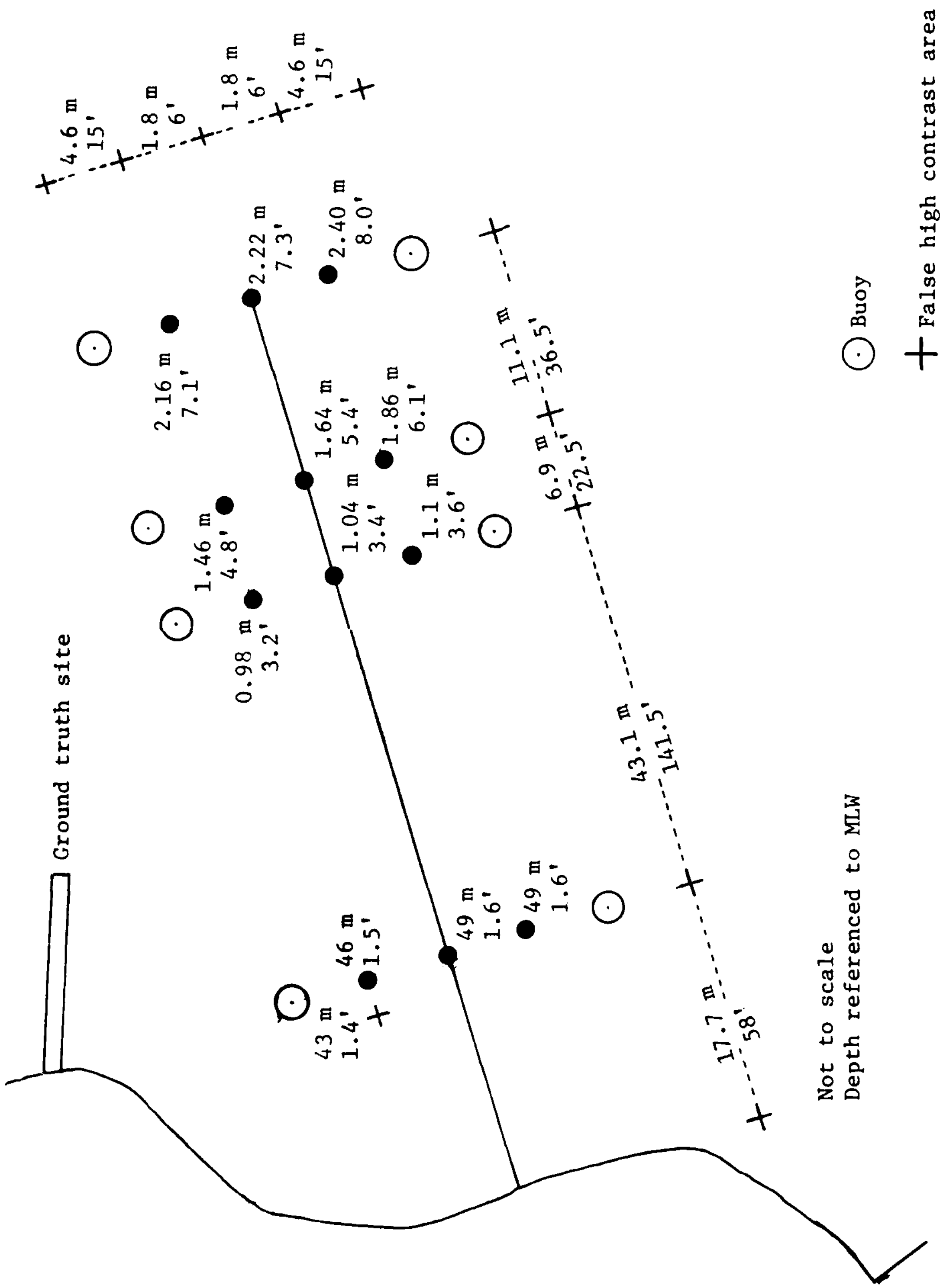


FIGURE 4. FIELD LAYOUT AT THE HELO PIER SITE ON 27 AUGUST 1981

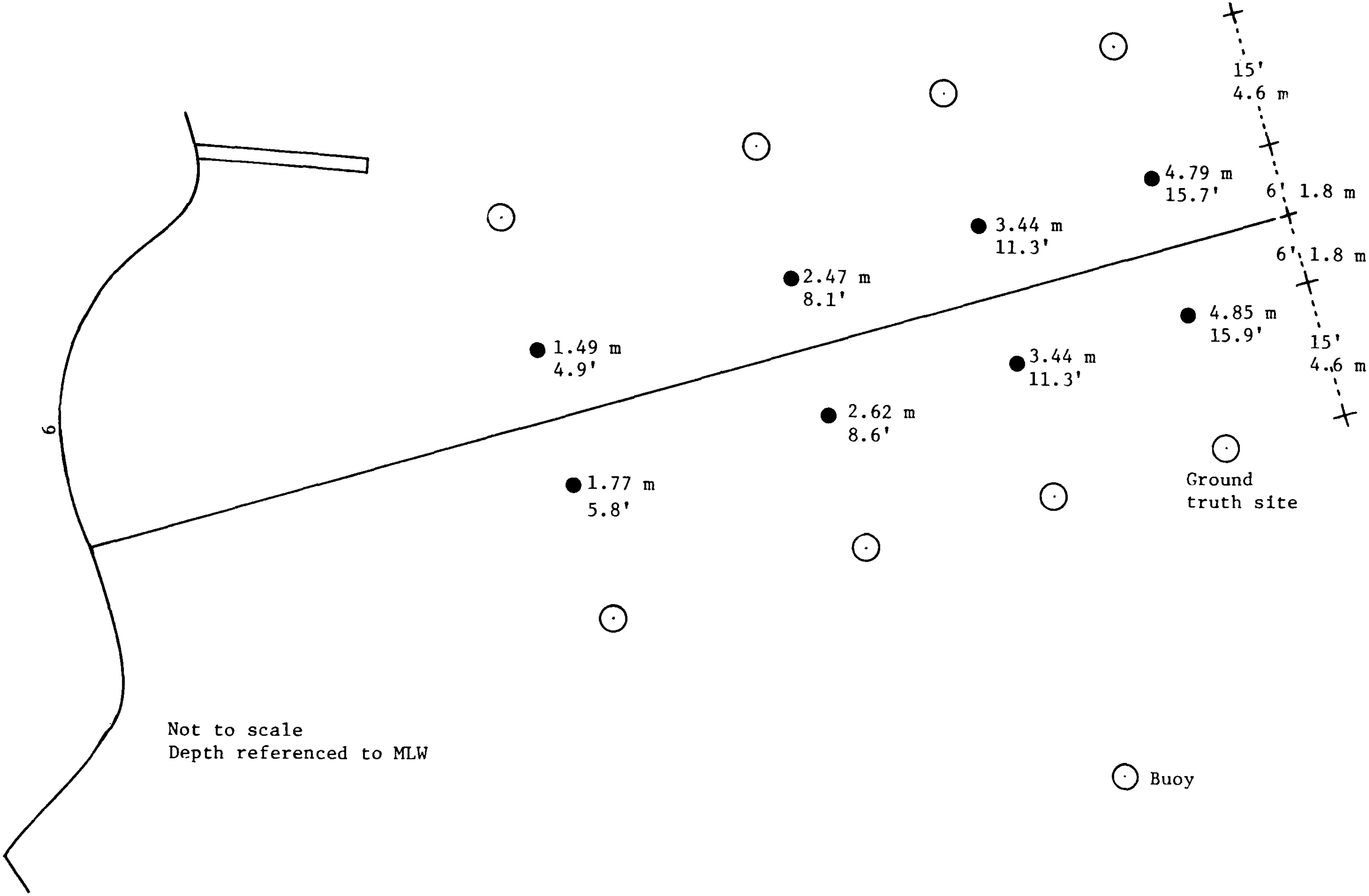
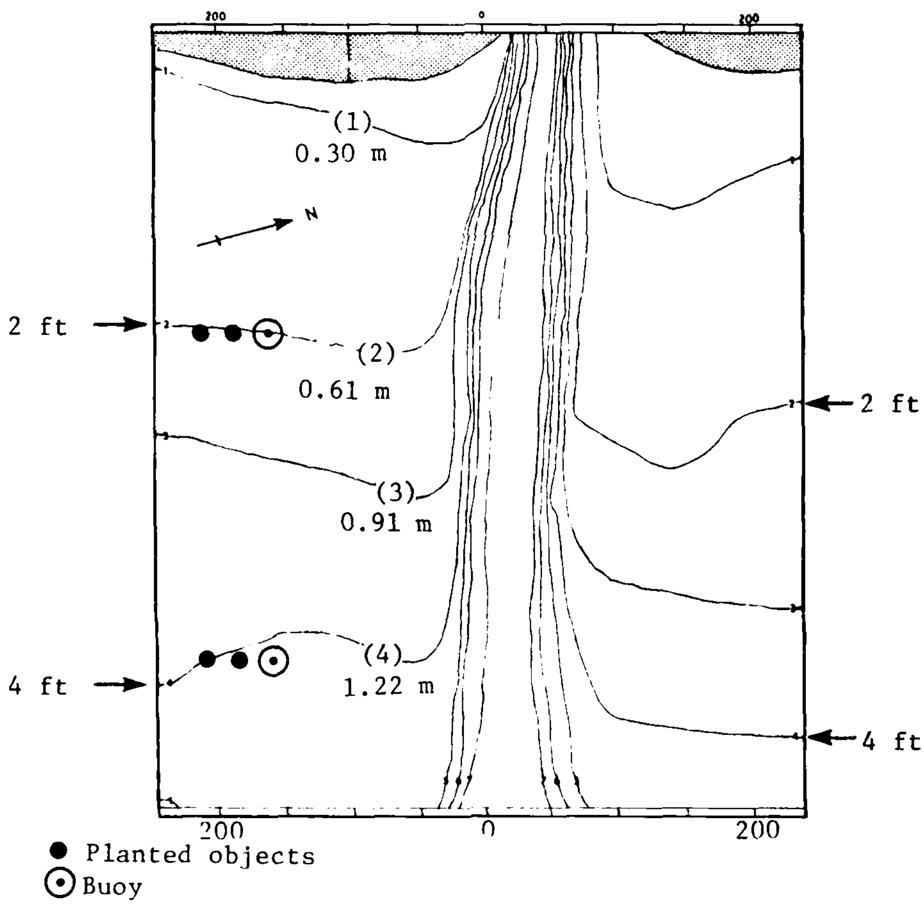


FIGURE 5. FIELD LAYOUT AT THE HELO PIER SITE ON 1 SEPTEMBER 1981

and painted international orange for contrast. Ground truth measurements were made from a pier just outside the test area and down current (on 27 August) and at the easternmost buoy (on 1 September).

During a preflight inspection of the test field on 27 August, a number of potential false high contrast areas were identified. The first was a 15-centimetre dark pipe extending from the bottom in 0.4 metre of water. Two others were located seaward and to either side of the 2.2-metre depth object. The false high contrast areas were bowl-shaped depressions approximately 0.45 to 0.6 metre in diameter filled with dead sea grasses and offering high contrast to the surrounding light colored sand.

The marina site layout is shown in Figure 6. Panels were identical to those at the helo pier site. Plates were 1.8 metres apart and buoyed on either end with international orange floats (4.6-metre separation from plates). All plates rested on marine grasses and virtually no contrast existed. Ground truth measurements were made at the eastern buoy located on the 1.2-metre bathytherm.



(DISTANCES EXAGGERATED FOR ILLUSTRATION PURPOSES)

FIGURE 6. TEST LAYOUT AT THE MARINA TEST SITE

INSTRUMENTATION AND MEASUREMENT TECHNIQUES

Instrumentation used for ground truth measurements is listed in Table 1. Certain instruments will be discussed to clarify the measurement technique and problems encountered.

TABLE 1

INSTRUMENTATION USED FOR GROUND TRUTH MEASUREMENTS

Parameter	Instrument	Supplier
Solar Radiance	Model 50 Eppley Pyroheliometer	Eppley Laboratory, Inc. Newport, Rhode Island
Alpha (α) Beam Attenuation Coefficient	Model XMS In Situ Transmissometer	Martek Instruments, Inc. Newport Beach, California
K Diffuse Attenuation Coefficient	Model 268WA350 Underwater Irradiance Meter	Kahl Scientific Instrument Corporation El Cajon, California
Surface Water Temperature	PRT-5 Precision Radiation Thermometer	Barnes Engineering Co. Stamford, Connecticut
Water Temperature	Bucket Thermometer	Kahl Scientific Instrument Corporation El Cajon, California
Wave Height	Surface Piercing Resistance Staff	Marsh-McBirney & Co. Gaithersburg, Maryland
Wind Speed/ Wind Direction	Wind Translator	Climet Redlands, California

Solar Radiance

Measurements of solar radiance were obtained by means of a Model 50 Eppley pyrometer (Serial No. 6630) connected to a battery powered recorder and single stage amplifier. The amplifier was designed to yield a 100 mV output that represented 2.0 cal/cm^2/min (1 solar constant) full scale. Since a very stable, shadow-free location was needed for these measurements, the instrument was placed at land sites not far from test areas. For the Gulf site, the pyrometer was situated 152 to 183 metres northeast of the buoyed area. In the bay, this distance was reduced to less than 30.5 metres. The instrument is generally trouble free but is sensitive to a weak battery or radio transmission; i.e., effects of amplifier.

Beam Attenuation Coefficient - Alpha (α)

Alpha is a measure of attenuation (due to absorption and scattering) of a collimated beam of monochromatic light traversing a fixed path of homogeneous water.[11] In-situ measurements of alpha over a 1-metre path length were made with a Martex Model XMS transmissometer [493-nanometre (nm) wavelength]. Data were recorded as percent transmission (%T) and converted to alpha by:

$$\alpha = \text{Ln}\,\frac{1}{\%\ T/100}\quad .$$

Measurements are not sensitive to platform motion and are highly reliable. However, the instrument should not be subjected to rough treatment such as small boat usage in heavy seas. The number and depths where alpha measurements were taken were dependent on water depth at the objects' location and available time. In most cases, measurements were obtained just below the water surface, mid-depth, and just off the bottom when depth exceeded 3.1 metres.

Diffuse Attentuation Coefficient - (K)

The diffuse attenuation coefficient (K) is a spectrally dependent characteristic that indicates the extent to which direct light diminishes exponentially with depth in water. K was measured with a Kahl underwater irradiance meter (Model 268WA350/T). The complete system consisted of a battery powered deck control module, a deck (ambient) cell, a sea cell unit, and supporting cables. Each cell consisted of a stabilized selenium photocell of 11 cm^2 (1.75 in^2) responsive area, special filters for wavelengths of interest, and a cosine collector to eliminate light variability due to angle of incidence. The cosine collector also acted as a neutral density filter with 10 percent transmission. Filters within the sea cell were 443, 520, 550, and 670 nm with ±10-nm bandwidth.

For our purposes:

$$K = \frac{\ln \text{radiance}_{d_2} / \ln \text{radiance}_{d_1}}{d_2 - d_1}$$

This measurement used available light and was severely influenced by intermittent cloud patterns and surface effects in low light levels. Extreme care was taken to ensure that the boat's shadow did not influence K measurements.

Both α and K were measured since each provides a measure of water clarity; but significant differences exist, however, between the two quantities. α offers the advantages of being a well-defined, reproducible measure

[11]Van Norden, M. F. and Litts, S. E., "The Transparency of Selected US Coastal Waters with Applications to Laser Bathymetry," Thesis, Naval Postgraduate School, September 1979.

of absorption and scattering regardless of illumination or depth. In addition, the measurement can be taken equally well night or day. There are two disadvantages: (1) a series of readings is required to describe a water mass as a single value (depth averaged α or $\bar{\alpha}$) and (2) all scattered light is regarded, conceptually, as gone.

The measurement of K is completely dissimilar since K represents an integration of the water column between the surface and sensor into a single quantity. This quantity for homogenous waters varies with depth and depends on the diffusivity of solar illumination at the time of measurement. The advantages K offers include automatic integration of water column into a single quantity and scattered light at small collective angles is retained as a light fraction in measurement. Alternatively, K is hard to measure at night and is dependent on the diffusivity of solar illumination at the time of measurement. K as a water clarity measure is also more sensitive to the presence of "yellow substance" dissolved in bay waters and can be used to define a surface wedge of fresh water runoff floating on higher density seawater.

Obviously, both quantities yield valuable information about the water column. When possible, both units should be measured simultaneously so that the utility of K is retained along with the rigor and night capability of α.[12]

The remaining instrumentation was standard water quality instruments whose use is self explanatory.

FIELD TEST OF 27 AUGUST 1981

The initial test was performed on 27 August 1981 at the helo pier test site. Ground truth measurements were obtained at the helo pier during the interval from noon to 1445 CDT (Central Daylight Time). Surface measurements were taken for α, K, tidal variation, solar radiation, wind speed and direction, and water temperature. No wave gauge was available in the immediate area; however, readings were taken from a gauge located 16 kilometres seaward.

Weather

The 0700 CDT weather map indicated poor visibility (3 to 4 miles) with medium rain. Winds were 1 to 3 knots from the east or northeast. Cloud cover ranged from 25 percent (Tallahassee) to 100 percent (Mobile). Air temperature was 73°F (22.7°C).

Locally, the sky was overcast with diffuse solar radiation (Figure 7). Scattered thunderstorms moved through the test area bringing a misty rain and increasing sea surface roughness. Winds were from the east-northeast (Figure 8) throughout the day at speeds ranging from 12 to 18 knots (1430 CDT).

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[12] Guenther, G. C. and Goodman, L. R., "Laser Applications for Near-Shore Nautical Charting," NOS Papers, 22nd Technical Symposium, Society of Photoptical Institute Engineering, San Diego, CA, 31 August 1978.

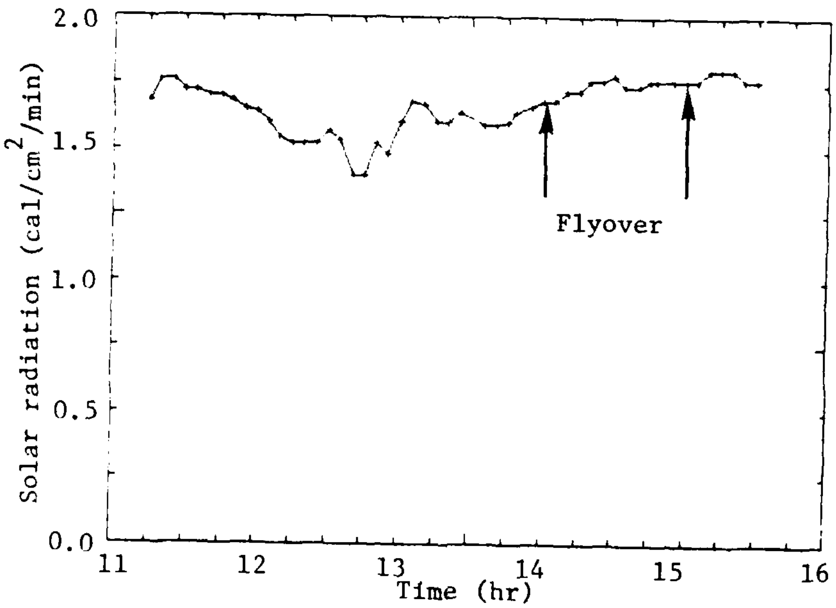

FIGURE 7. SOLAR RADIATION ON 27 AUGUST 1981

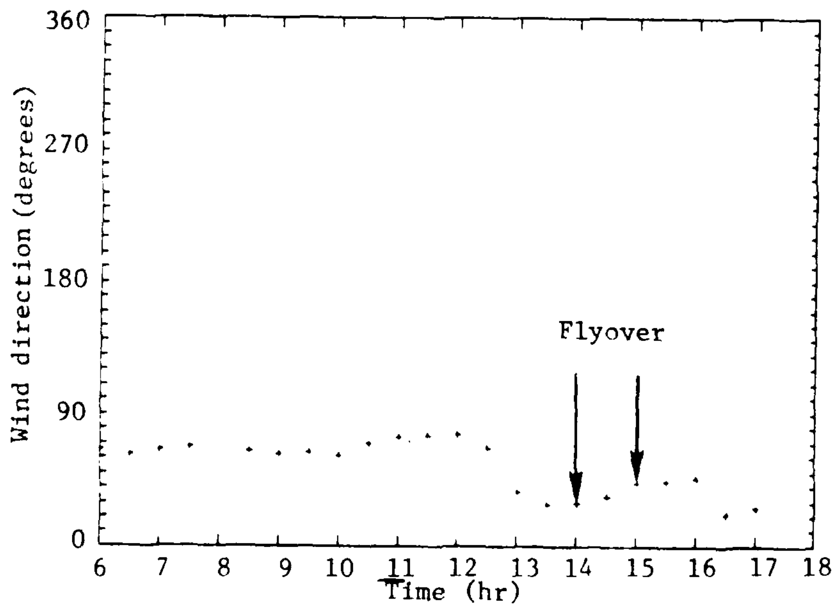

FIGURE 8. WIND DIRECTION ON 27 AUGUST 1981

During the actual flyover (1400 to 1500 CDT), wind speed was increasing (Figure 9).

Water Column Parameters

The predicted water level/tidal curve for 27 August is plotted in Figure 10. Plotted are values predicted for tidal height as well as observed water level variation. Values as plotted represent tidal heights at Pensacola. For the test area, 32 minutes must be subtracted from the time for each reading. These data represented the tidal extreme for August. During the actual flyover, however, less than 7.6 centimetres of water could be attributed to tide.

Wave activity was significant with white caps occurring in the channel. Near-shore waves were less than 1 foot in height and gradually diminishing. Steady winds from the east-northeast tended to drive waves into the test area reducing underwater visibility.

Surface water temperature, as recorded by the PRT-5, was erratic but a gradual decrease was evident (Figure 11). The variability was attributed to wave activity and associated turbulence on the sea surface coupled with cool air temperatures produced from thunderstorms.

Measured values of alpha are listed in Table 2. The results indicated very poor visibility ($\alpha = 2.9$ per metre at 1215 CDT). The poor values resulted from steady winds throughout the morning that produced significant wave action. Visibility increased slightly ($\alpha = 2.36$ per metre at 1354 CDT) but decreased to $\alpha = 2.66$ per metre at 1408 CDT as weather deteriorated. Alphas normally range between 1.2 to 3 per metre in St. Andrew Bay. Values approaching 3 are associated with rain and runoff.

The diffuse attentuation coefficient (K) was variable throughout the test period but indicated poor visibility (Table 2). When measured values of K at each wavelength are plotted according to Jerov's water types (Figure 12),[13] it was apparent that the bay water for August was type 7 or 8, coastal water. By definition, these waters are highly colored and turbid with reduced underwater visibility. Greatest variability was in the red region (670 nm) due to sea surface roughness and turbidity variations.

Due to the shallow water (2 metres) at the helo pier site, K was measured at 1 metre only. This prevented an assessment of water mass types or visibility layers that may have been present. In addition, a depth averaged K could not be calculated.

FIELD TEST OF 31 AUGUST 1981

On 31 August, operations shifted to the Gulf site located just seaward of NCSC's Beach Tower II. Ground truth measurements were made at the buoys which

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[13] Jerlov, N. G., Marine Optics. Elsevier Oceanography Series, No. 5, New YorK: Elsevier Publishing Co., 1976.

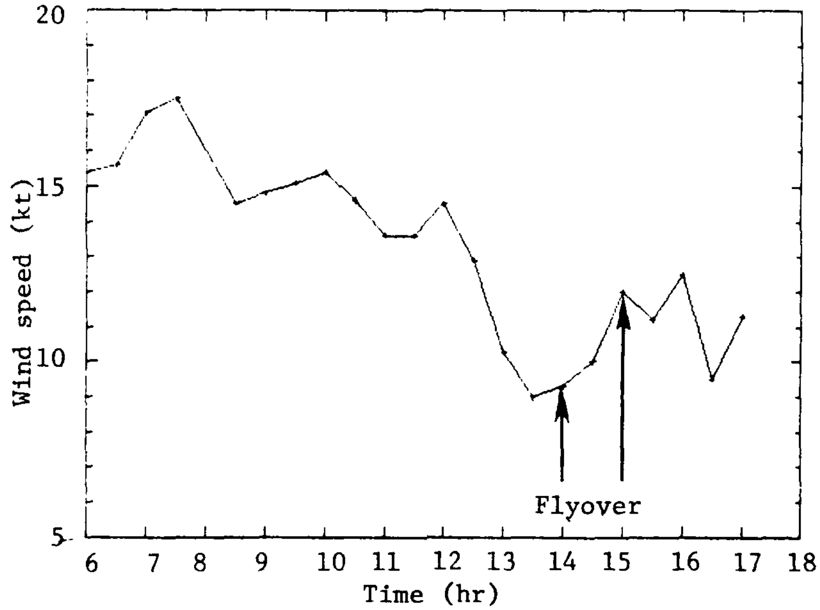

FIGURE 9. WIND SPEED ON 27 AUGUST 1981

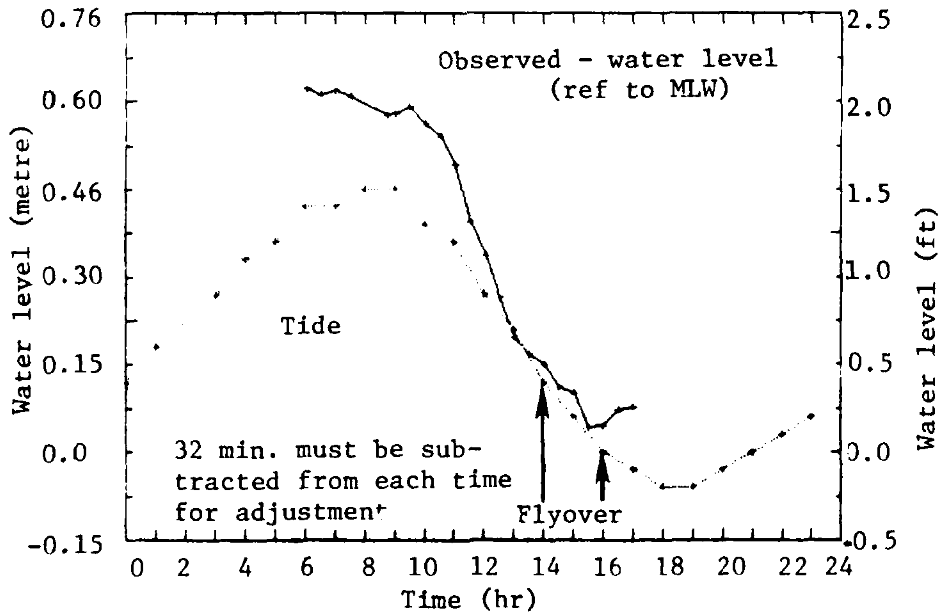

FIGURE 10. WATER LEVEL/TIDAL CURVE ON 27 AUGUST 1981

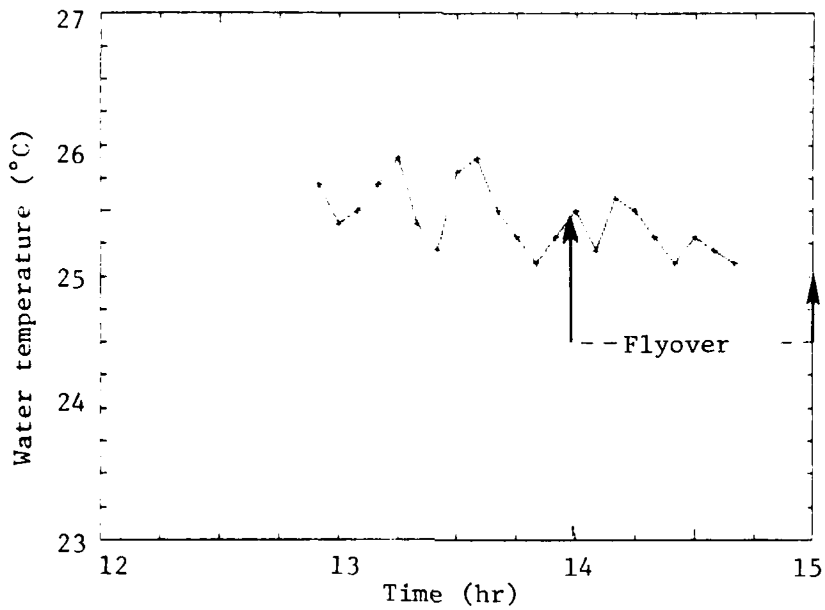

FIGURE 11. SURFACE WATER TEMPERATURE ON 27 AUGUST 1981

TABLE 2

MEASURED OPTICAL PARAMETERS AT THE HELO PIER TEST SITE ON 27 AUGUST 1981

	K (Wavelength)				
Time CDT	Red 670 nm	Green 520 nm	Blue 443 nm	Clear 550 nm	α Surface
1215					2.900
1307	0.759	0.731	0.906	0.626	
1330	0.644	0.819	0.863	0.751	
1354					2.364
1400	0.552	0.789	0.829	0.671	
1408					2.659
1430	0.538	0.736	0.817	0.672	

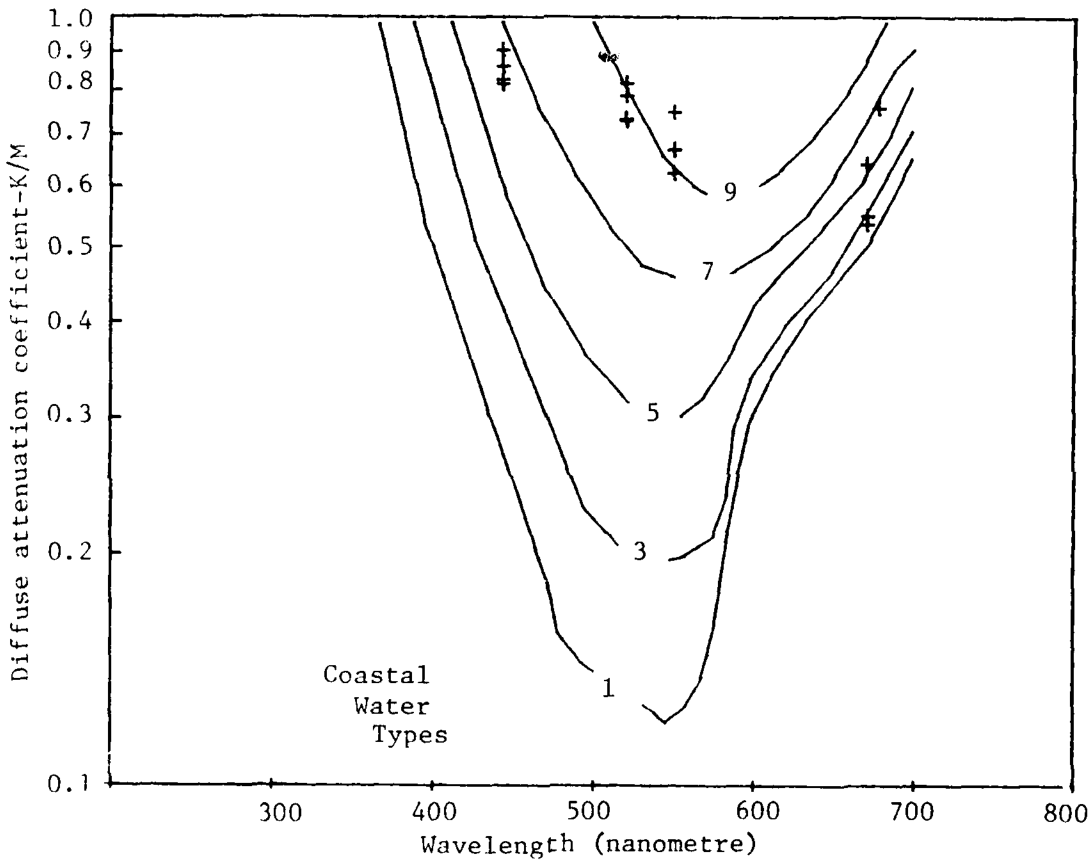

FIGURE 12. DETERMINATION OF JERLOV WATER TYPE IN 27 AUGUST BAY TEST

marked the locations of objects at 11.0-, 7.2-, and 3.6-metre depths. Measurements of α, K, secchi depth, tidal variation, wind speed and direction, solar radiation, water temperature at surface 3 metres, and wave height were obtained.

Weather

Significant levels of rain fell during the weekend bringing a heavy influx of turbid runoff to bay and near-shore Gulf waters. On 31 August, the weather chart (0700 CDT) showed visibilities ranging from 11.3 kilometres (Mobile) to 400 metres (Tallahassee) with heavy rain falling to the east of Panama City. Cloud cover ranged from 100 percent at Tallahassee to 50 percent at Mobile. Weather conditions are not charted in Panama City.

While local skies were sunny, heavy cloud masses were present throughout the day. The effect of clouds is evident in Figure 13 where a sharp increase in solar radiation is followed by spikes of various duration. The duration that solar radiation levels are depressed indicate the presence of very large cloud masses and a great areal coverage of the sky by the cloud masses. Maximum solar radiation occurred around 1200 CDT when the radiation levels exceeded one solar constant. Two failures in the data recording system produced gaps in the data as shown in the figure. Ground truth measurements of solar radiation indicated that light available to the passive sensor was reduced in magnitude and varied in intensity from moment to moment.

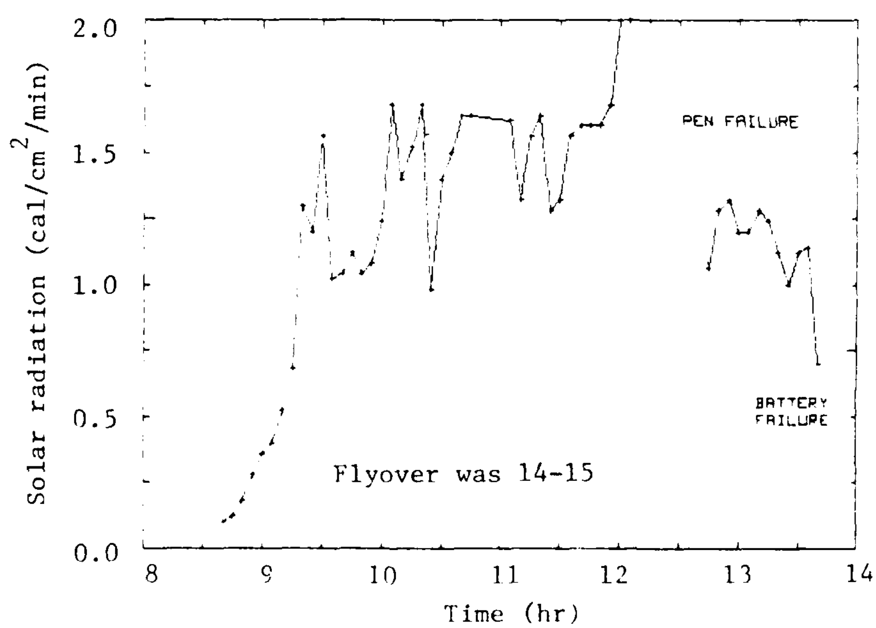

FIGURE 13. SOLAR RADIATION ON 31 AUGUST 1981

Winds posed yet another problem on this date. During the early morning, winds were relatively weak (Figure 14) and from the north (Figure 15). These winds tended to counteract the normal south-southeast surface wave patterns usually present in the test area thereby contributing to a calm sea. By 1000 CDT, however, the wind shifted to the south-southwest and increased gradually throughout the day. Winds of 10 to 11 knots prevailed during the actual flyover. Water mass movement generated by surface winds can influence underwater visibility by stirring up bottom sediments and can occur even to depths of 25 metres. Sustained winds of 15 knots (7.71 m/sec) will significantly increase turbidity. When winds abate to less than 10 knots (5.14 m/sec), turbidity may begin to diminish. However, turbidity levels usually remain somewhat high for several (one to two) days thereafter.[9]

Water Column Parameters

The predicted water level and tidal range for 31 August 1981 is plotted in Figure 16. Tide range was generally less than 1 foot during this period. During the afternoon, the tidal level was falling but added approximately 0.2 metre to depth measurements during the flyover.

Underwater visibility was severely reduced by wave action on this date. Throughout the day, wave height averaged about 0.8 metre (Figure 17). The wave picture was further complicated by the presence of 0.3- to 0.5-metre swells from the south-southeast. Interactions between this swell and local wind-generated surface waves produced seas which varied from 0 to 1.2 metres in height. The waves exerted their main effect on the sandbar where significant sediment entrainment occurred. Water in the lower 1.8 to 2.4 metres of the water column was thus very turbid.

Surface water temperatures measured by PRT-5 increased sharply between 1350 and 1400 CDT (Figure 18). Some variation occurred in temperature, but by 1430 CDT surface conditions were so rough that a constant surface water temperature was observed. A somewhat different picture is afforded by Figure 19. These temperatures were measured at a depth of 3 metres and showed the effect of solar heating. Although some variation was evident, water temperature remained relatively constant during the period 1300 to 1500 CDT.

Alpha measurements are listed in the last three columns of Table 3. Measurements were made at three stations (at the 11.0-, 7.2- and 3.6-metre depth contours) and, depth permitting, 1 metre below the water surface, 5 metres, and 1 metre above the bottom. Listed values of alpha were somewhat higher than usual for local Gulf coastal waters. In general, visibility was better offshore than near the surf zone. Measurements made at the various depths for each station indicated the presence of at least two different water masses. The turbid bottom layer was generated by wave motion in the surf zone and the consequent increase in suspended particulates. This layer, later observed by divers, was approximately 2.1 to 3.0 metres thick and decreased in thickness as water depth increased (i.e., offshore distance increased).

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[9] ibid.

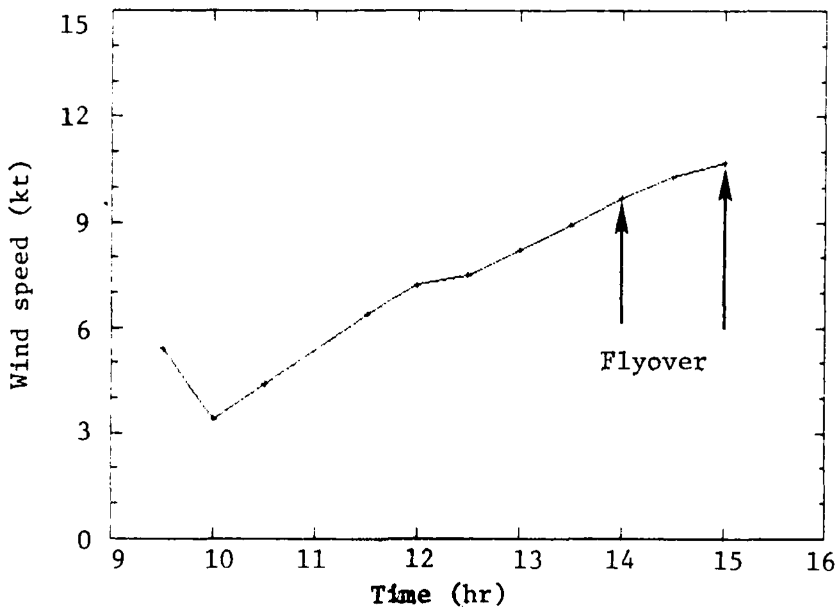

FIGURE 14. WIND SPEED ON 31 AUGUST 1981

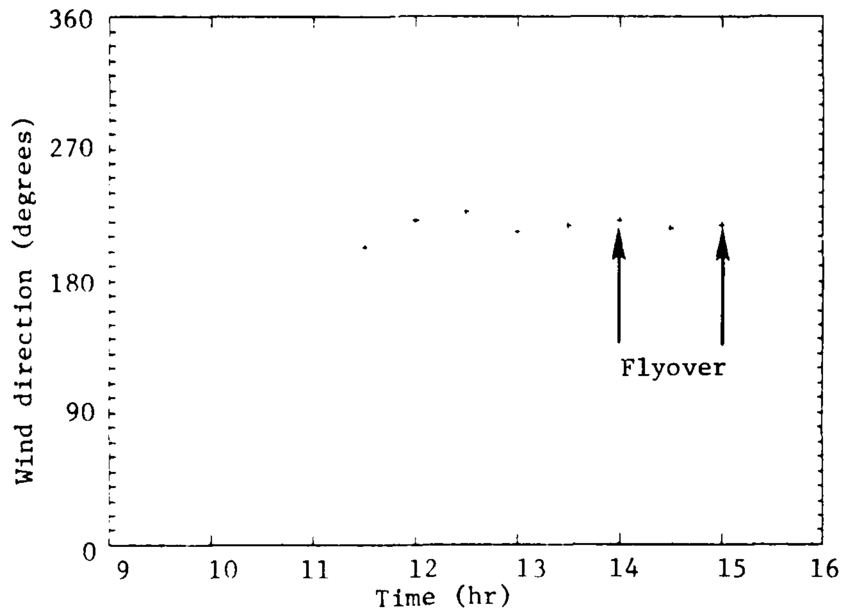

FIGURE 15. WIND DIRECTION ON 31 AUGUST 1981

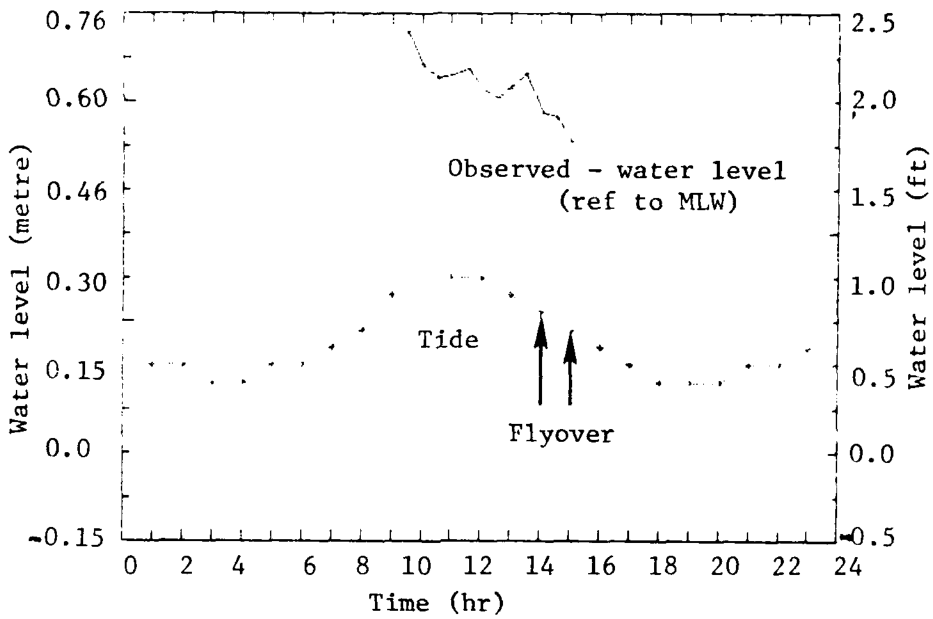

FIGURE 16. WATER/TIDE LEVEL ON 31 AUGUST 1981

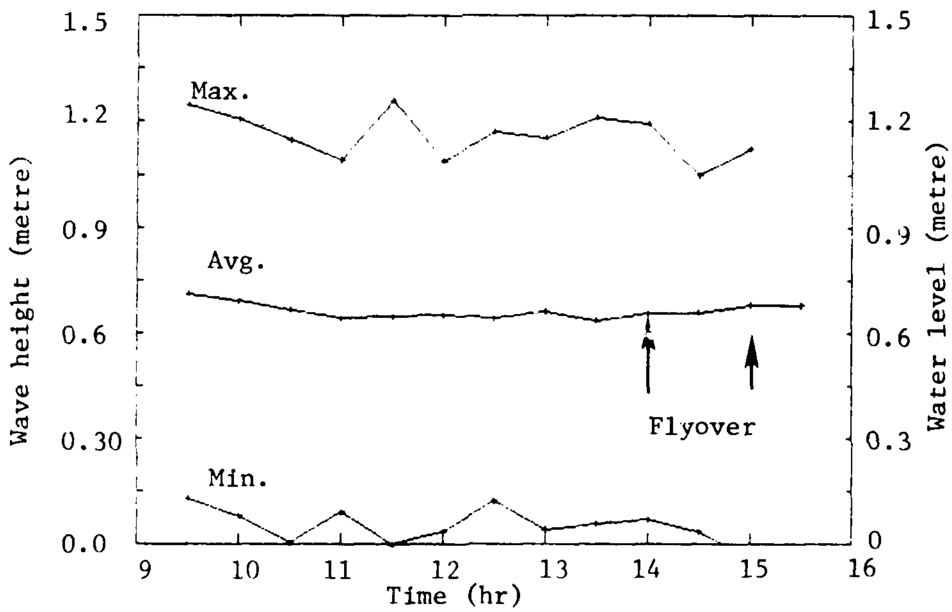

FIGURE 17. WAVE HEIGHT ON 31 AUGUST 1981

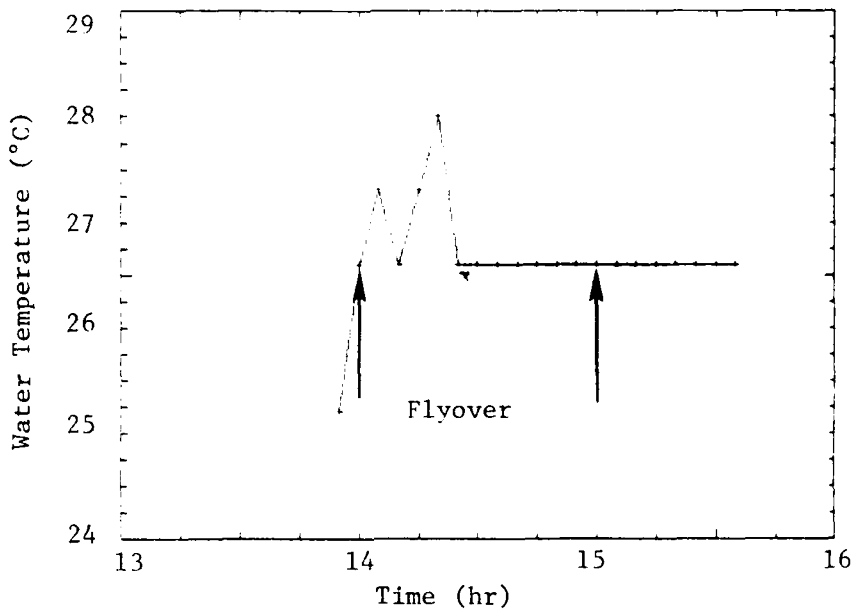

FIGURE 18. SURFACE WATER TEMPERATURE ON 31 AUGUST 1981

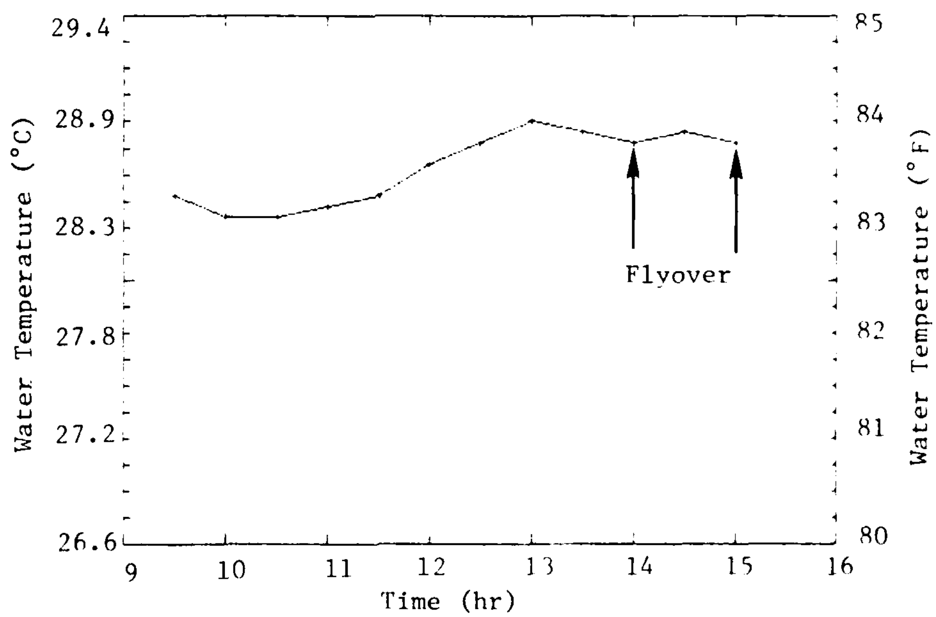

FIGURE 19. WATER COLUMN TEMPERATURE ON 31 AUGUST 1981

TABLE 3

MEASURED OPTICAL PROPERTIES AT GULF STATIONS
ON 31 AUGUST 1981

		K (Wavelength)				α		
Time CDT	Station (m)	Red 670 nm	Green 520 nm	Blue 443 nm	Clear 550 nm	Depth (m) 1	5	Depth-1
1408 S	4.6	3.150	1.280	0.234	0.370			
B		0.470		0.083	0.268			
1410	6.1					0.416	0.580	ND
1426 S	7.6	0.747	0.419	0.327	0.318	0.580	0.968	1.08
B		0.560	0.057	0.374	ND			
1445	9.1					0.478	0.580	0.654
1454 S	10.7	1.525	0.633	0.425	0.788	0.616	0.654	ND
B		0.095	0.132	0.234	0.182			
1521 S	12.2	0.866	0.767	0.431	0.754	0.844	ND	ND
B		0.095	0.090	0.146	0.177			

Measured diffuse attenuation coefficient values are also listed in Table 3. K was measured at four selected wavelengths by determining radiance values 1 metre apart in depth at both the surface and bottom. High values of K were caused by extensive rains that occurred during the preceding four days and the consequent runoff containing large amounts of the so-called yellow substance; e.g., tannic and humic acid. The mechanism whereby bay waters move by advection into the test area was described by Austin and Payne.[14] In essence, easterly winds diverted ebbing bay waters toward the west, causing a plume of rather turbid brown-green water to spread across the surface of the test area. Such waters would yield high values of K in both the red (670 nm) and green (520 nm) wavelengths. This water would move offshore and west of the jetties trapping clearer water along shore until wind-generated waves mixed the water types. When values of K near the bottom are compared to surface K, it is evident that the water column contained two water mass types. The water column could be described as turbid bay water overlying somewhat cleaner Gulf water. The variety of water masses becomes self evident when K is plotted versus wavelength (Figure 20) in order to identify Jerlov water type.[13] The spread in data indicated that no one water type predominated in the test area and thus significant mixing was occurring between bay and Gulf waters.

[13] Ibid.

[14] US Navy Mine Defense Laboratory Report 165, "Results of a Field Study of the Tide Line Mechanism," by G. B. Austin and R. H. Payne, March 1962.

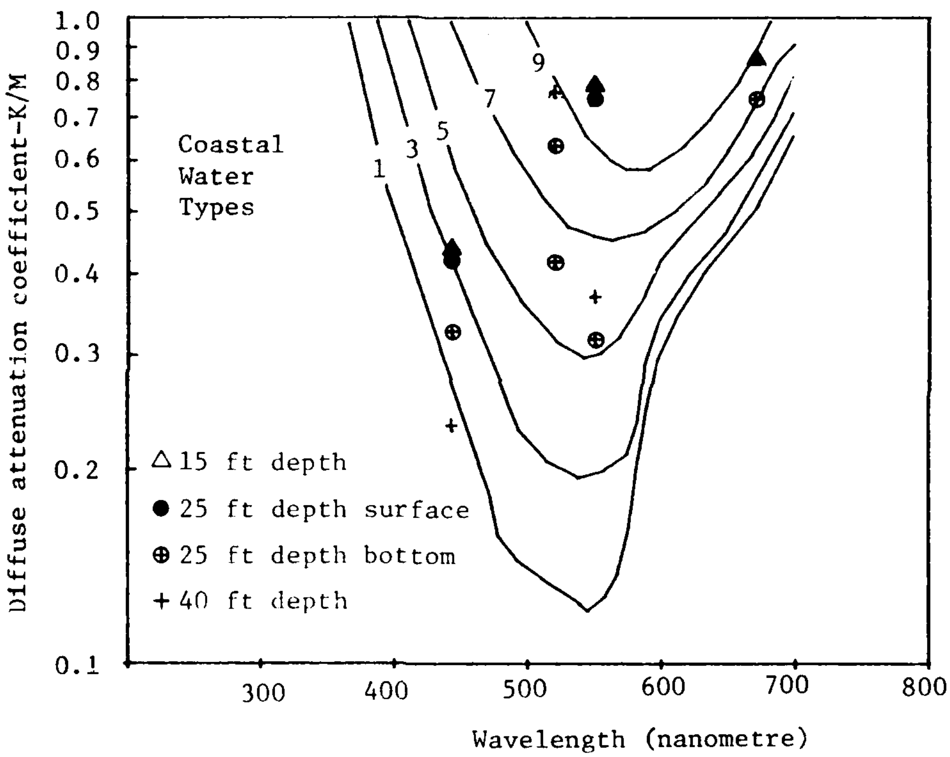

FIGURE 20. DETERMINATION OF JERLOV WATER TYPE IN 31 AUGUST GULF TEST

By comparing α and K measurement results, it was evident that the gulf water column on 31 August consisted of (1) dirty bay water floating on the surface, (2) somewhat cleaner gulf water at mid-depth, and (3) highly turbid gulf water near the bottom. Such a water column presents special difficulties in remote sensing applications. Obviously, depth average values of K and α are required to describe the water column as a single measurement. However, time limitations did not allow such detailed measurements for this experiment.

FIELD TEST OF 1 SEPTEMBER 1981

The final field test was conducted on 1 September 1981 at both gulf and bay sites with flyovers at 8 to 10 and 14 to 15 hours. Due to the distance between test sites and the short duration of flyovers, ground truth measurements were limited to a single set of optical readings at each site; and the usual observations of solar radiation, tidal variation, wind speed and direction, wave height at gulf site only, and water temperature at the gulf site on the surface and at 3 metres.

Weather

Visibility ranged from 21.1 to 37 kilometres with a medium rain occurring to the east of Panama City. Winds were generally light (<3 knots) and from the east-southeast. Cloud cover ranged from 100 percent in Mobile, Alabama, to 25 percent in Tallahassee, Florida.

Locally, the weather was similar to that of the previous day, 31 August. The sky was sunny but large cloud masses were present during the morning and early afternoon (Figure 21). Solar radiation began to increase just prior to the gulf flyover (0806 CDT). The irregular increase in solar radiation denotes the presence of large cloud masses while the duration of sunlight repression provides an estimate of areal sky coverage by the clouds. Data loss between 1000 and 1100 CDT was caused by RF interference from a radio transmitter located near the pyroheliometer site. Skies were clearing in the late afternoon bringing a sharp increase in solar radiation and warm air temperatures. At no time did solar radiation exceed 1.5 $cal/cm^2/min$ (3/4 solar constant). This represents a 25 percent decrease in available light recorded by the sensor on the previous day.

Wind speeds were generally weak (6 to 9 knots) in the early morning (Figure 22) and from the north (Figure 23). By 0830 CDT, winds began to shift from the north to the west and decreased to 4 knots. Wind increased steadily thereafter, reaching 9 knots at 1400 CDT. A southwesterly sea breeze prevailed from 1100 CDT throughout the afternoon.

Water Column Parameters

The predicted tide curve and observed water level variation is plotted in Figure 24. For 1 September, the predicted tide ranged from 12.2 to 24.4 centimetres. During the gulf flyover (0800 CTD), tide was responsible for less than 15.2 centimetres depth. This increased to 19.8 centimetres depth at the bay-helo port site (0930 CDT) and 21.3 centimetres depth at the bay-marina site (1000 CDT).

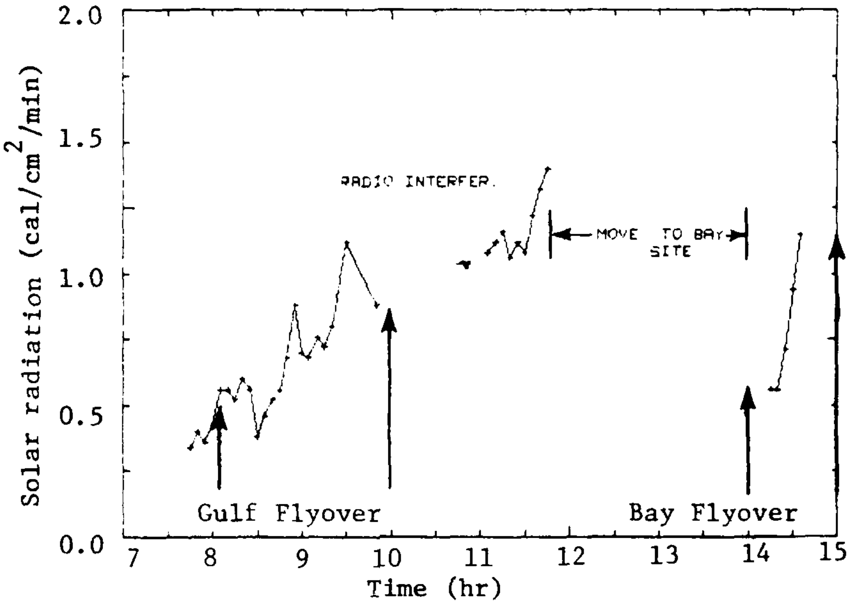

FIGURE 21. SOLAR RADIATION ON 1 SEPTEMBER 1981

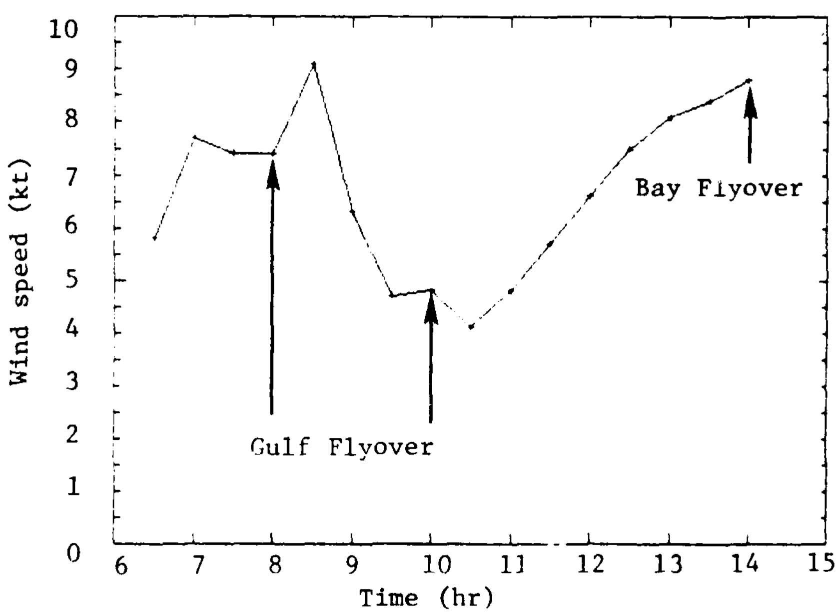

FIGURE 22. WIND SPEED ON 1 SEPTEMBER 1981

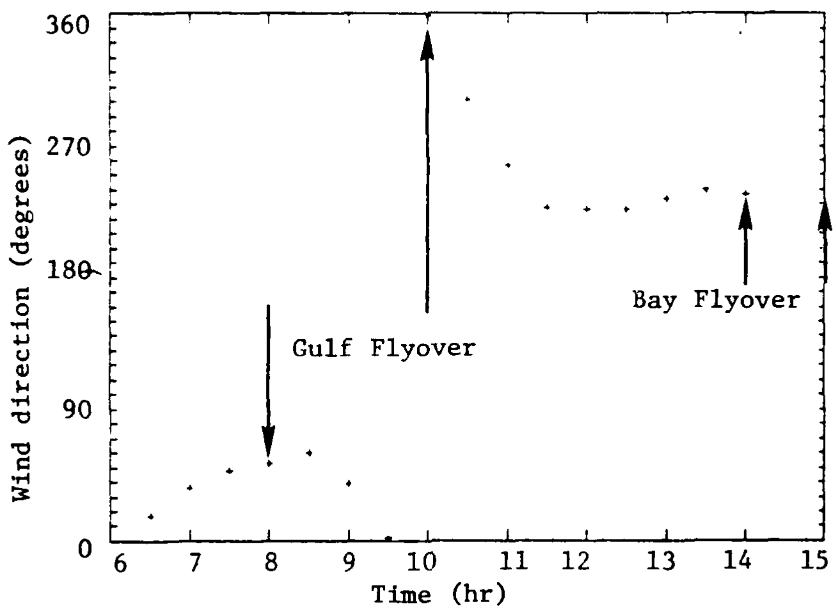

FIGURE 23. WIND DIRECTION ON 1 SEPTEMBER 1981

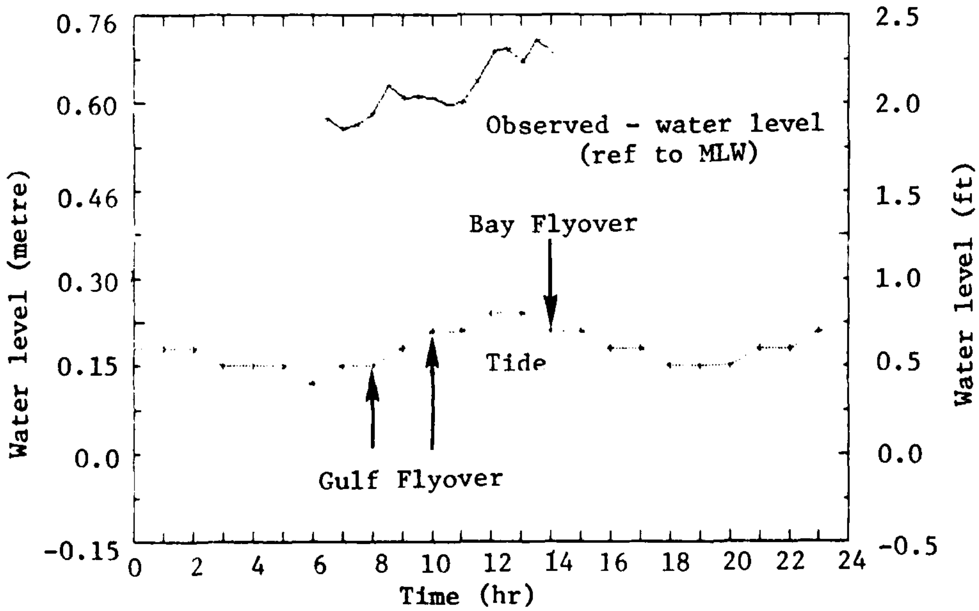

FIGURE 24. WATER LEVEL/TIDE ON 1 SEPTEMBER 1981

Waves in the Gulf were a function of wind speed, wind direction, and swell activity. Swells were generally low (<0.5 metre) and from the east-southeast. Wind-generated waves averaged 0.5 metre in height ranging from 0.2 to 1.0 metre (Figure 25). Throughout the day, there was a gradual increase in maximum wave height, probably due to the increasing wind speed. The corresponding wave motion kept shallow water stirred up and reduced underwater visibility.

The recordings show that the surface water temperature was near 25°C (Figure 26) during the period of the Gulf flyover. Little variation was seen or expected due to continual wave-induced mixing that occurred. No measurements were made of the surface water temperature at either bay site (marina or helo pier). Instead, soil temperature measurements were made in response to a request from the Airborne Mine Countermeasures Department (Code 722). Initial soil temperatures were high due to solar heating under clear afternoon skies. However, soil surface temperatures decreased approximately 10°C during the interval aircraft hovered over the monitored area.

Gulf water temperatures at a depth of 10 feet decreased during the early morning hours to a low of 28.3°C (83°F) at 0800 CDT, then gradually increased to a high of 29.3°C (84°F) (Figure 27).

Alpha measurements for 1 September are listed in the last three columns of Table 4. At Gulf stations, it was apparent that the water column was stratified with a layer of turbid bay water overlying somewhat cleaner Gulf waters. Near the bottom, wave action had stirred up significant amounts of suspened material. This is clearly seen when transmissivity is plotted versus depth for the near-shore and sea stations (Figure 28). The major difference between the sea station (11 metres) or the near-shore station (7.6 metres) was that the latter was located closer to the sandbar where wind-generated waves exerted their maximum effect on the bottom. This was evident from the extremely high alpha values near the bottom (α = 2.813 per metre) at the 7.6-metre depth. When α values for 31 August and 1 September are compared (Table 5), little difference was noted in readings made 1 metre below the surface. However, surface α measurements at both stations and at 5-metre depth were significantly better on 1 September than 31 August. Bottom observations indicated a slight increase in visibility at the deeper station (11 metres) and a severe reduction in visibility occurred at the shallow station (7.6 metres). Again, the shallow station was located closer to the bar from which wave action was eroding sedimentary material. Surface values at bay stations (Table 4) were consistent with the expected range of 1.2 to 3.0 per metre. The bay value of 3.21 (5 m at heloport) indicated a two-layered water mass severely disturbed in the lower layer. Objects at 1.5-metre depth could not been seen by swimmers floating on the water's surface. Thus, visibility was extremely poor.

Diffuse attentuation data are also listed in Table 4. Measurement techniques were consistent with those of 31 August. Values of K differed considerably from those obtained on 31 August especially in the red and green wavelengths. This suggests significant reduction (i.e., dilution) in the amount of yellow substance in local waters. The reduction in light penetration through turbid waters is evident when K values are compared from gulf and

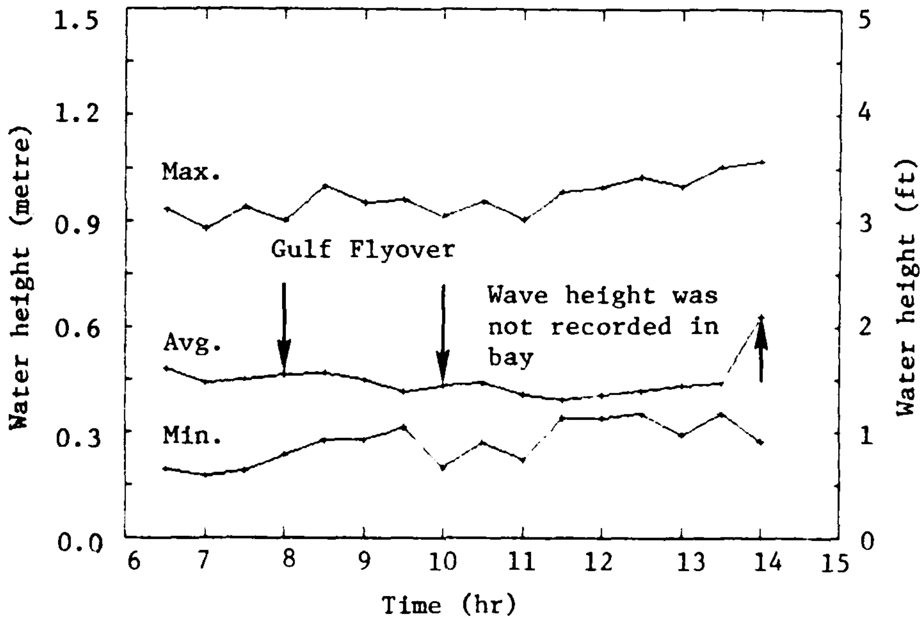

FIGURE 25. WATER HEIGHT ON 1 SEPTEMBER 1981

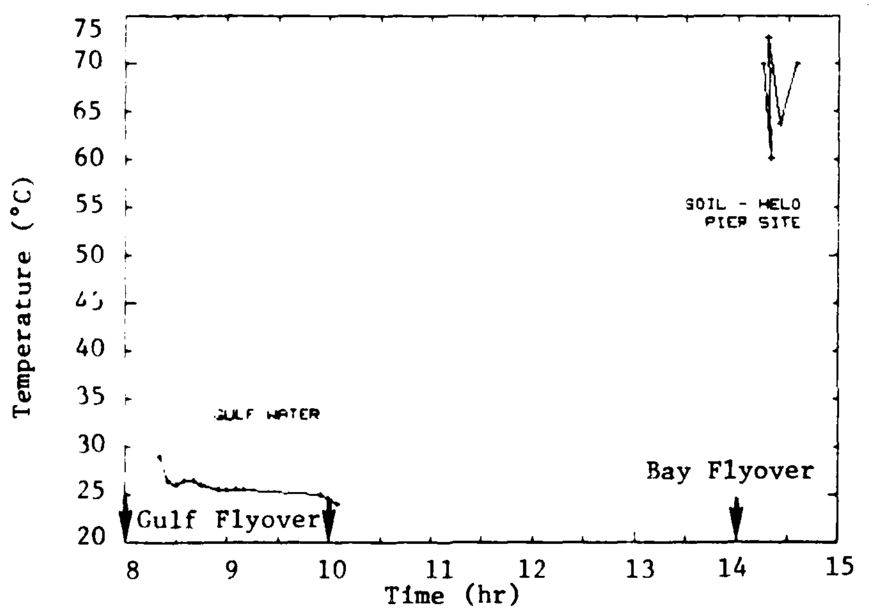

FIGURE 26. SURFACE WATER AND SOIL TEMPERATURE ON 1 SEPTEMBER 1981

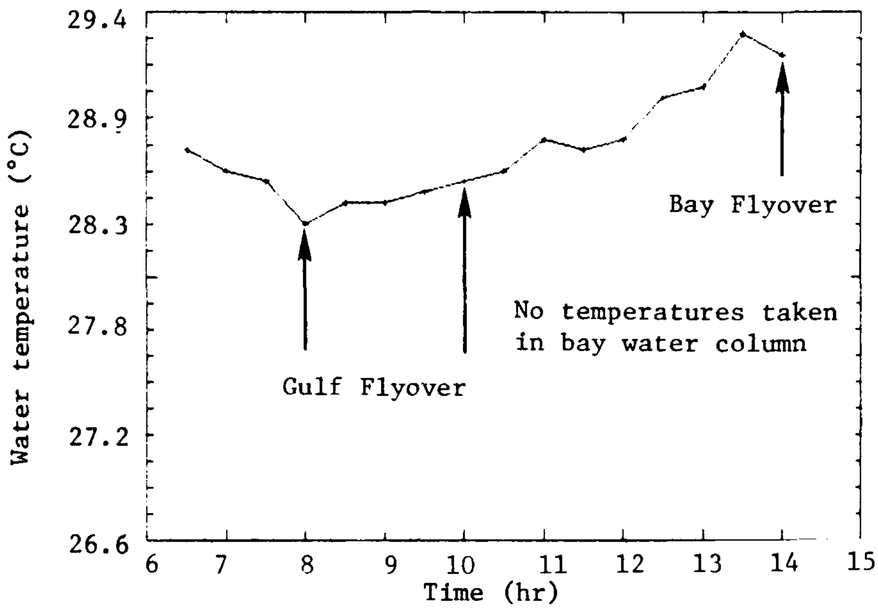

FIGURE 27. WATER COLUMN TEMPERATURE ON 1 SEPTEMBER 1981

TABLE 4

MEASURED OPTICAL PROPERTIES AT TEST SITES
ON 1 SEPTEMBER 1981

		K (Wavelength)				α		
Time CDT	Station	Red 670 nm	Green 520 nm	Blue 443 nm	Clear 550 nm	Depth (m) 1	5	Bottom
0816 S	Gulf	0.609	0.412	0.223	0.275	0.478	0.462	0.597
B	(11 m)	0.287	0.154	0.198	0.364			
0836 S	Gulf	0.472	0.434	0.357	0.190	0.562	0.478	2.813
B	(7.6 m)	0.201	0.194	0.171	0.288			
0939 S	Bay	0.793	0.631	0.639	0.466	1.200	3.210	ND
	Heloport	0.560	0.629	0.511	0.324			
1002 S	Bay-Marina	0.607	0.588	0.703	0.566	1.110	ND	ND

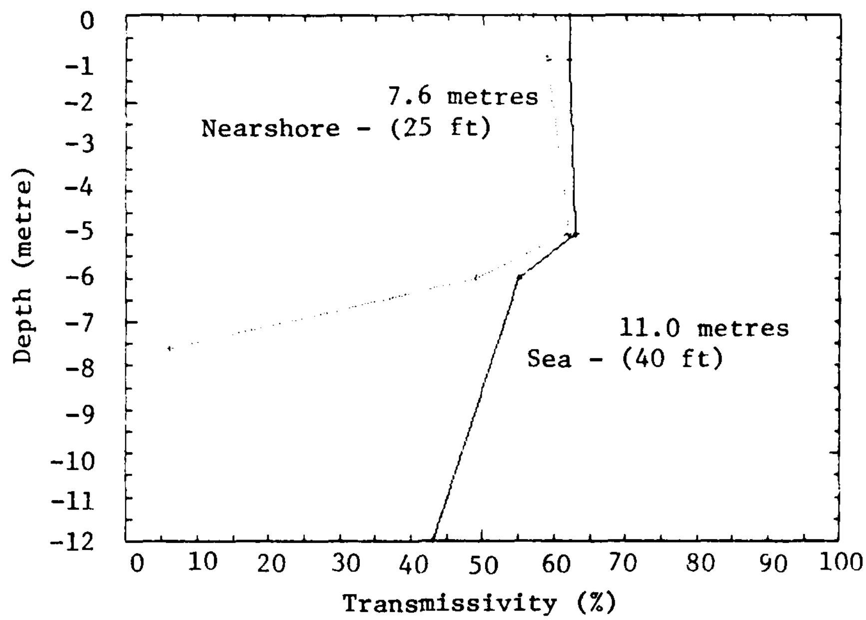

FIGURE 28. TRANSMISSIVITY ON 1 SEPTEMBER 1981

TABLE 5

COMPARISON OF α VALUES AT GULF STATIONS FROM MEASUREMENTS TAKEN 31 AUGUST AND 1 SEPTEMBER

	α (Depth)					
	1 metre		5 metres		Bottom - 1 m	
Station	31 Aug	1 Sep	31 Aug	1 Sep	31 Aug	1 Sep
12.0 m	0.478	0.478	0.580	0.462	0.654	0.597
7.6 m	0.580	0.562	0.968	0.478	1.080	2.813

bay waters (Figure 29) for Jerlov water types.[13] Results indicate that during the tests, gulf waters ranged from a coastal water type 2 to a coastal water type 5, whereas bay waters were coastal type 7. The presence of bay water as a surface layer floating on gulf water is obvious in plots of K versus wavelength (Figure 30). Regardless of whether the sea (11 metres) or near-shore (7.6 metres) station is plotted, K values for bottom measurements are invariably better than surface measurements. The turbid surface layer acted like a filter severely reducing light levels in the clearer water at depth. Essentially, the same situation prevailed within the bay. When K for surface and bottom measurements at the heloport are plotted (Figure 31), it is evident that the bottom water allowed better diffuse light penetration than surface water.

Water clarity is dynamic and quickly changes in response to local conditions. A good example is seen when the percentage penetration of diffuse light is plotted versus wavelength. Percentage penetration equals

$$\%P = \frac{\text{illumination at depth}_\lambda}{\text{illumination at surface}_\lambda} * 100$$

for each depth and wavelength of interest. Figure 32 shows results obtained on two successive days at the bay station (helo pier - buoy station). Note that there is little difference between 31 August and 1 September except that visibility (for 520 nm wavelength) at 1-metre depth had decreased on the second day. This was probably due to cumulative wave effects and associated turbulence extending turbidity further off the bottom.

A more striking example is seen for the near-shore Gulf station on 31 August and 1 September (Figure 33). Visibility at 520 nm significantly increased on 1 September for 1 metre and surface readings. And, to a lesser extent, the visibility at 550 nm also increased for 5- and 6-metre depths. A different picture was seen at the offshore or sea site located in 40 feet of water (Figure 34). Here visibility was less on the second day for the surface reading, but there was an increase in visibility at 550 nm at 5-metre depth. These results are due to wind stress and particulate settling. The first process caused movement of water masses, thus affecting surface or near-surface measurements. Readings on 31 August were made in the late afternoon when the sea breeze was well developed and had pushed bay waters, riding on the surface of denser and somewhat cleaner Gulf waters, on shore. Note that Gulf near-shore (Figure 32) and bay waters (Figure 33) are strikingly similar. At night, the sea breeze abated and was replaced by mild northerly winds driving turbid near-shore waters further offshore. Thus, the cleaner waters seen inshore on 1 September represent replacement of turbid, inshore waters by cleaner Gulf waters, not settling of particulate matter. This effect was observed by Hoge, et al, in their Chesapeake Bay Studies.[9] The 1 September

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[9]ibid.

[13]ibid.

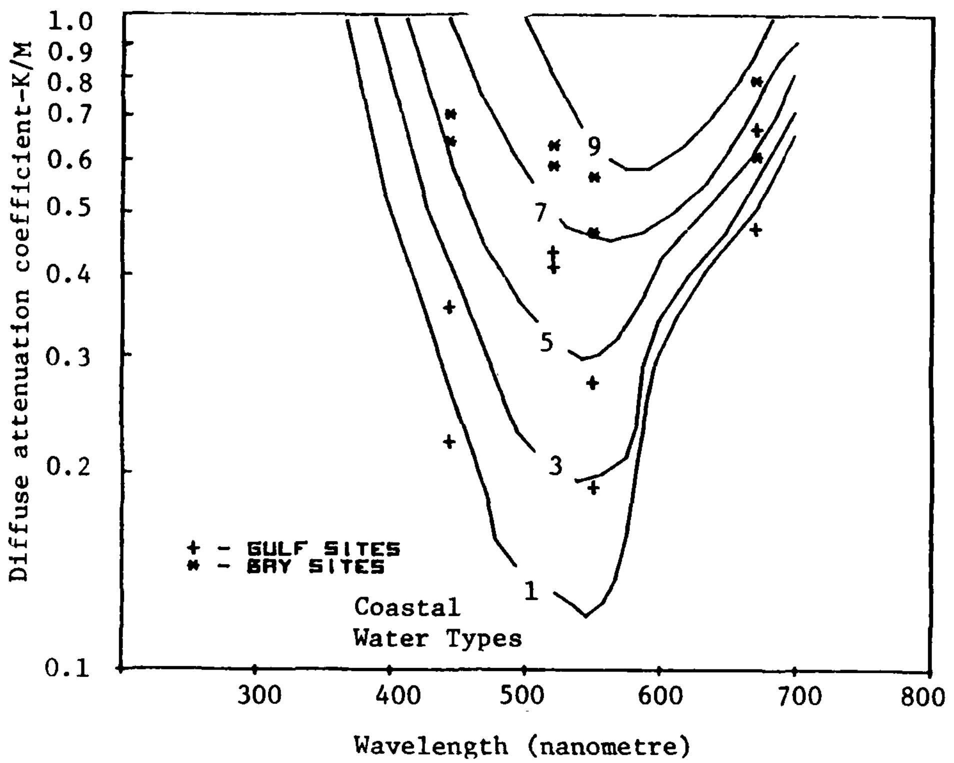

FIGURE 29. DETERMINATION OF JERLOV WATER TYPE IN 1 SEPTEMBER GULF AND BAY TESTS

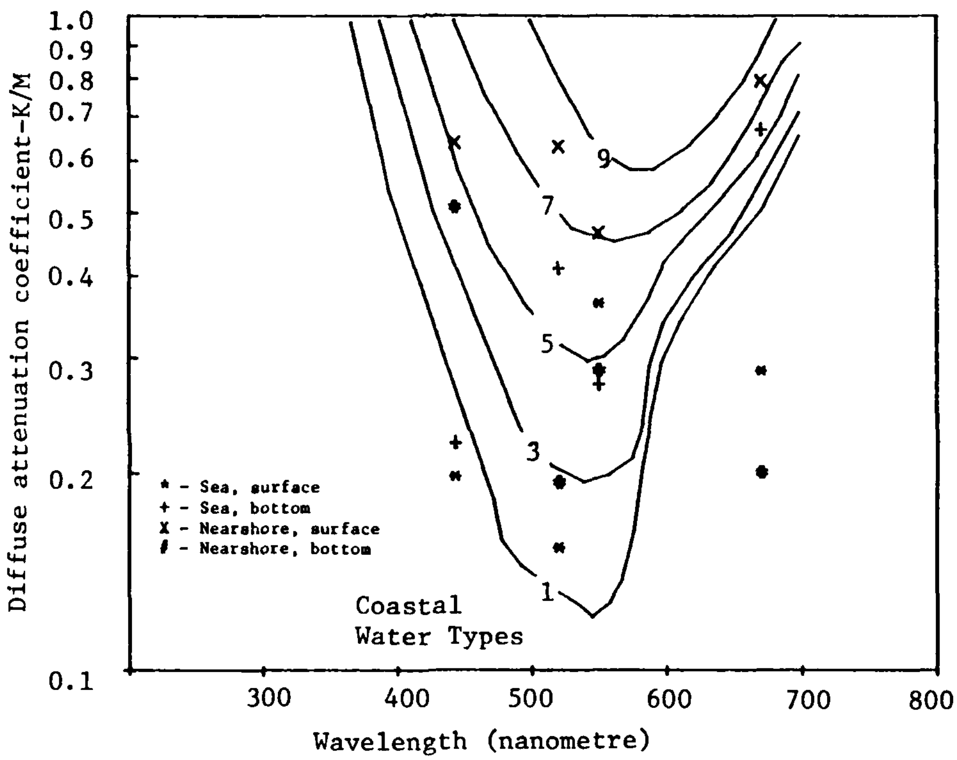

FIGURE 30. LOCATION OF VARIOUS JERLOV WATER TYPES IN [illegible] SEPTEMBER GULF TESTS

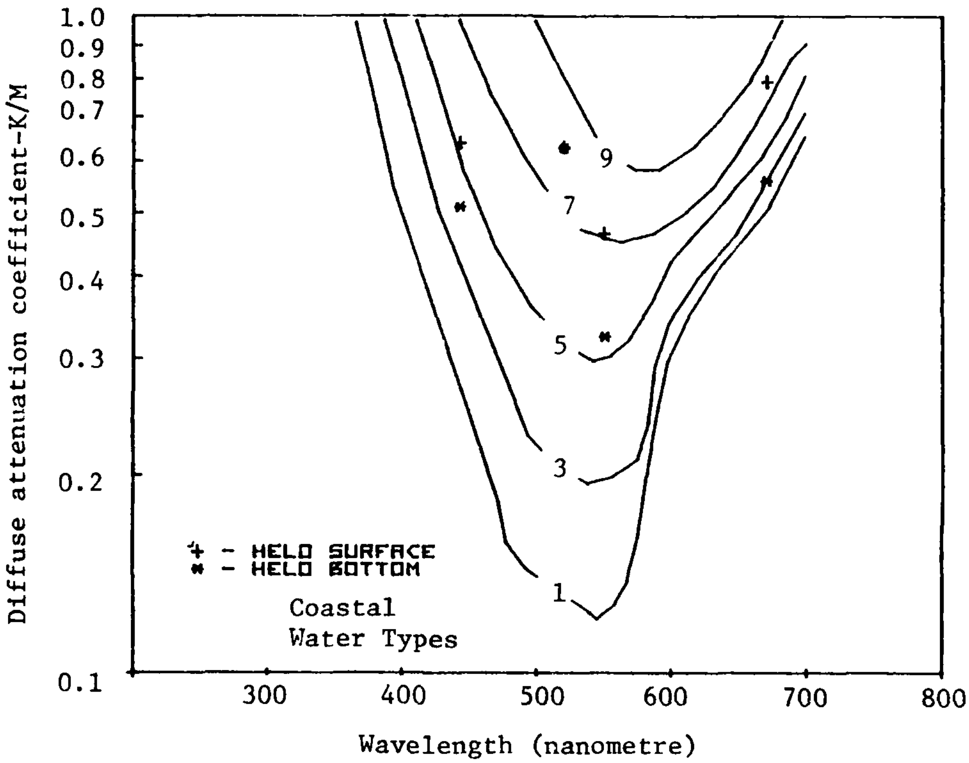

FIGURE 31. DETERMINATION OF WATER MASS TYPES AT HELO PIER TEST SITE IN 1 SEPTEMBER BAY TEST

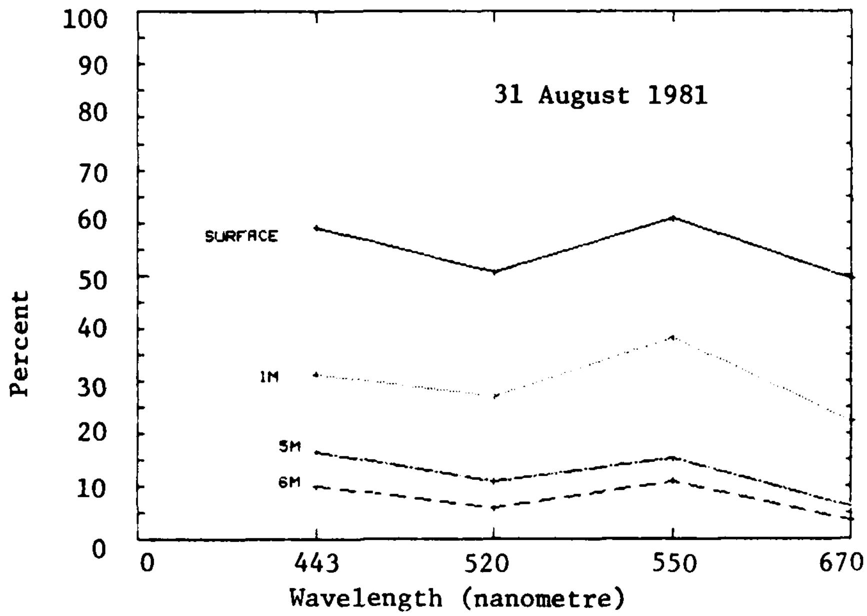

FIGURE 32a. PERCENT PENETRATION OF DIFFUSE LIGHT AT THE HELO PIER TEST SITE

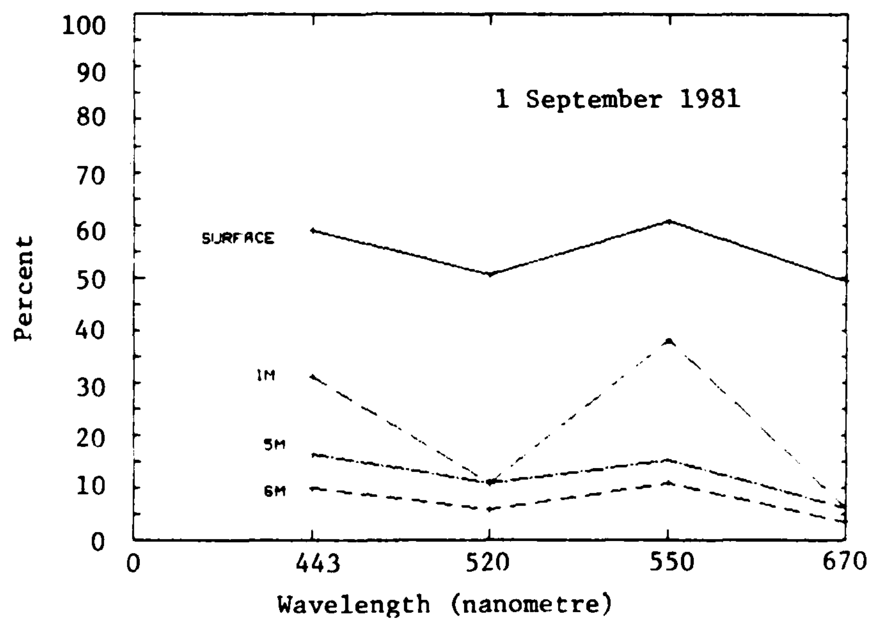

FIGURE 32b. PERCENT PENETRATION OF DIFFUSE LIGHT AT THE HELO PIER TEST SITE

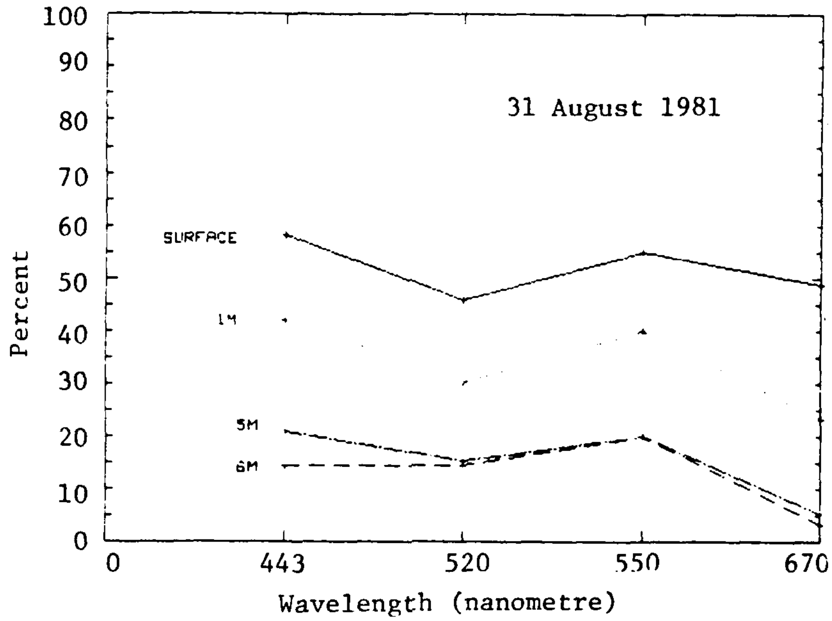

FIGURE 33a. PERCENT PENETRATION OF DIFFUSE LIGHT AT THE NEAR-SHORE (25-FOOT) GULF STATION

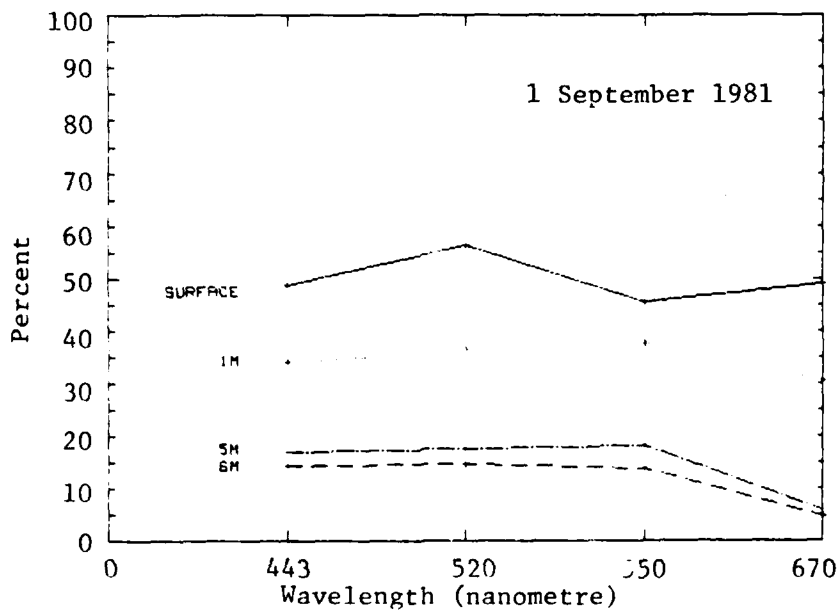

FIGURE 33b. PERCENT PENETRATION OF DIFFUSE LIGHT AT THE NEAR-SHORE (25-FOOT) GULF STATION

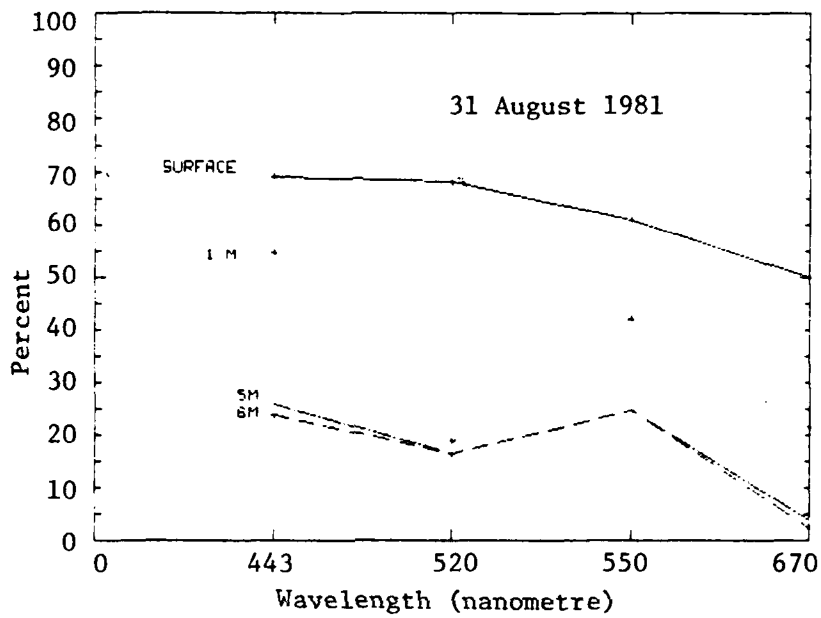

FIGURE 34a. PERCENT PENETRATION OF DIFFUSE LIGHT AT THE OFFSHORE (40 FOOT) GULF STATION

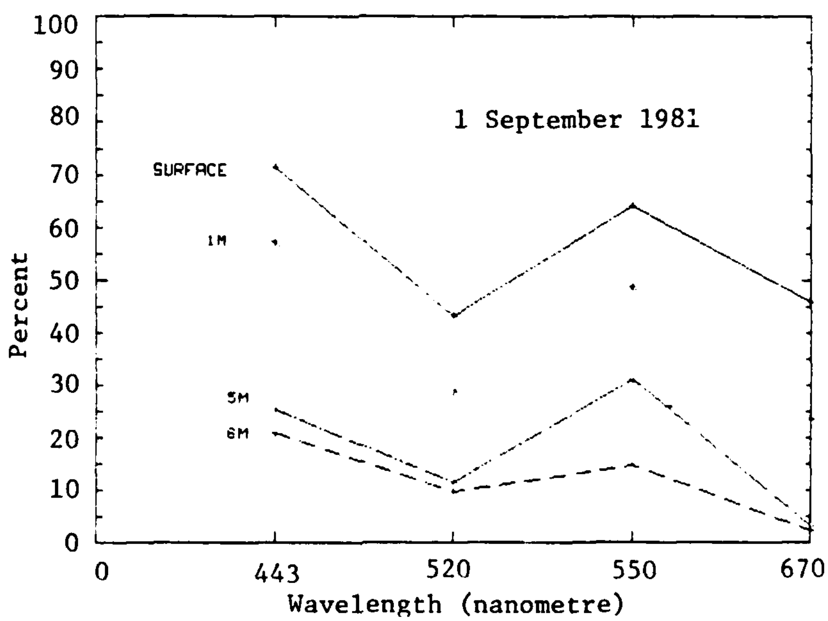

FIGURE 34b. PERCENT PENETRATION OF DIFFUSE LIGHT AT THE OFFSHORE (40 FOOT) GULF STATION

readings were made in the morning prior to wind shifting from the north and sea breeze development. Once the sea breeze developed, bay water was pushed near shore.

The second process, particulate settling, is indirectly dependent on winds. As the winds moderate (<10 knots), the waves moderate, turbidity decreases, and visibility increases. As waves decrease, there is not enough turbulence to keep particulates suspended. This is evident in Figures 33 and 34. On 31 August, there was no difference in the amount of light reaching 5 or 6 metres at 550 nm. However, by 1 September there was a slight increase in light reaching 5 metres (Figures 33). This can also be seen to a greater extent in Figure 34 for the same depths and wavelength. The increase in visibility results from particulate settling that, in effect, compacts the turbidity layer over time. If sufficient time elapses prior to wind and wave recurrences, the turbidity layer will continue to contract increasing the percentage of light penetration to depth.

RECOMMENDATIONS

These recommenations should improve future tests:

1. Tests should be conducted during the latter stage of rising tides to minimize the effects of turbid bay waters. If more stringent (i.e., dirtier water) conditions are required, tests should be conducted during an ebb tide.

2. Tests should not be conducted within two days of severe frontal passages.

3. Adequate time should be allowed before, during, and after each flyover for sufficient measurements to be taken to compute depth-averaged α and K.

4. Tests should be performed prior to 1000 CDT to minimize sea breeze effects.

5. Make more use of historical data for planning test dates and locations.

6. There should be more effort to determine the effects of changing weather and seasons on optical conditions of local water.

7. Instrument capability should be upgraded for performing in-situ optical measurements stressing portability, battery operation, compatibility for small boat operations, easy field calibration and filter changeability, and automatic recording of essential measurement.

Acceptance of these recommendations should improve the quality of test data and facilitate scheduling of future tests during optimal periods.

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